# Document 4
# Asset Category – G&P Transformers
# SPN

Asset Stewardship Report 2014

Andrew Stephen

## Approved by Richard Wakelen / Barry Hatton

## Approved Date 03/03/2014

## Document History

| Version | Date | Details | Originator | Revision Class | Section Update |
|---|---|---|---|---|---|
| 1.1 | 21/02/2014 | Updated costs and volumes | Andrew Stephen | Minor | 1.1, 1.3, 7.4.1, 7.4.2, 7.5.3, Appendix 5 |
| 1.2 | 21/02/2014 | Modified Appendix 7, added Appendices 8, 9 &10 | Andrew Stephen | Minor | Appendices 7, 8, 9 &10 |
| 1.3 | 24/02/2014 | Preface added | Andrew Stephen | Minor | Preface |
| 1.4 | 25/02/2014 | Update all HI data | Andrew Stephen | Minor | 1.3, 4.7, 7.2.1, 7.6.2, Appendix 2 |
| 1.5 | 26/02/2014 | Remove risk matrices<br><br>Update data references | Andrew Stephen | Minor | 7.6.2<br><br>Appendices |
| 1.6 | 27/02/2014 | HI Tables Updated | Andrew Stephen | Minor | 7.2.1 |
| 1.7 | 03/03/2014 | Editing grammar<br><br>Data points added to Figure 10 | Andrew Stephen | Minor | Preface, 7.5.1<br><br>3.5.3 |
| 1.8 | 03/03/2014 | Reference to Appendix 9 added | Andrew Stephen | Minor | 1.3 |
| 2.0 | 04/03/2014 | Approved by Barry Hatton | Andrew Stephen | Major | |

# Preface

UK Power Networks uses Asset Stewardship Reports ('ASR') to describe the optimum asset management strategy and proposals for different groups of assets. This optimised asset management strategy and plan details the levels of investment required and the targeted interventions and outputs needed. Separate ASRs define the most efficient maintenance and inspection regimes needed and all documents detail the new forms of innovation which are required to maximise value, service and safety for all customers and staff throughout the ED1 regulatory period. Outline proposals for the ED2 period are also included.

Each DNO has a suite of approximately 20 ASR's. Although asset policy and strategy is similar for the same assets in each DNO the detailed plans and investment proposals are different for each DNO. There are also local issues which must be taken into account. Accordingly each DNO has its own complete set of ASR documents.

A complete list of titles of the ASR's, a summary of Capex and Opex investment is included in '**Document 20: Asset Stewardship Report: Capex/Opex Overview'**. This document also defines how costs and outputs in the various ASR's build up UK Power Networks 'NAMP' (Network Asset Management Plan) and how the NAMP aligns with Ofgem's ED1 RIGs tables and row numbers.

Where 'HI' or asset 'Health Index' information is included please note predicted ED1 profiles are before any benefits from 'Load driven investment.'

This ASR has also been updated to reflect the feedback from Ofgem on our July 2013 ED1 business plan submission. Accordingly to aid the reader three additional appendices have been added. They are;

1. **Appendix 8 Output NAMP/ED1 Business Plan Data Table Reconciliation:** This section explains the 'line of sight' between the UKPN Network Asset Management Plan (NAMP) and the replacement volumes contained in the Ofgem RIGS tables. The NAMP is the UKPN ten year rolling asset management investment plan. It is used as the overarching plan to drive both direct and indirect Capex and Opex interventions volumes and costs. The volume and cost data used in this ASR to explain our investment plan is taken from the UK Power Networks NAMP. Appendix 8 explains how the NAMP outputs are translated into the Ofgem RIGS tables. The translation of costs from the NAMP to the ED1 RIGS tables is more complex and it is not possible to explain this in a simple table. This is because the costs of a project in the 'NAMP' are allocated to a wide variety of tables and rows in the RIGS. For example the costs of a typical switchgear replacement project will be allocated to a range of different Ofgem ED1 RIGs tables and rows such as CV3 (Replacement), CV5 (Refurbishment) CV6 (Civil works) and CV105 (Operational IT Technology and Telecoms). However guidance notes of the destination RIGs tables for NAMP expenditure and included in the table in the Section 1.1 of the Executive Summary of each ASR.

2. **Appendix 9 Efficiency benchmarking with other DNO's:** This helps to inform readers how UK Power Networks is positioned from a benchmarking position with other DNO's. It aims to show why we believe our investment plans in terms of both

volume and money is the right answer when compared to the industry, and why we believe our asset replacement and refurbishment investment proposals are efficient and effective and in the best interest for our customers.

3. **Appendix 10 Material changes since the July 2013 ED1 submission:** This section shows the differences between the ASR submitted in July 2013 and the ASR submitted for the re-submission in March 2014. It aims to inform the reader about the changes made to volumes and costs as a result of reviewing the plans submitted in July 2013. Generally the number of changes made is very small, as we believe the original plan submitted in July 2013 meets the requirements of a well justified plan. However there are areas where we have identified further efficiencies and improvements or recent events have driven us to amend our plans to protect customer safety and service.

We have sought to avoid duplication in other ED1 documents, such as ‘Scheme Justification Papers’, by referring the reader to key issues of asset policy and asset engineering which are included in the appropriate ASR documents.

## Contents

# 1.0 Executive Summary SPN 132kV and EHV Transformers

## 1.1 Scope

This document details UK Power Networks' non-load related expenditure (NLRE) replacement and refurbishment proposals for 132kV and EHV Transformers for the ED1 period. Indicative proposals for the ED2 period are also included.

There are 164 132kV Transformers in SPN with an estimated MEAV of £259m. The proposed investment including civils is £1.8m per annum, which equates to an average annual 0.71% of the MEAV for this category. There are 473 EHV Transformers in SPN with an estimated MEAV of £291m. The proposed investment including civils is £3.16m per annum, which equates to an average annual 1.09% of the MEAV for this category.

Replacement and refurbishment costs for these assets are held in the Networks Asset Management Plan (NAMP) and in sections of the RIGs tables identified in Table 1. Detailed reconciliation of asset removal volumes between RIGs and NAMP can be found in Appendix 8.

| Investment type | ED1 | NAMP line | RIGs reference |
|---|---|---|---|
| 132kV Transformers asset replacement | £10.3m | 1.51.01 | Additions<br>CV3 Row 101 – 132kV Transformer<br><br>Removals<br>CV3 Row 229 – 132kV Transformer |
| 132kV Transformers asset refurbishment | £1.4m | 1.51.11 | CV5 Row 52 – 132kV Transformer |
| EHV Transformers asset replacement | £13.9m | 1.51.03 | Additions<br>CV3 Row 83 – 33kV Transformer (GM)<br><br>Removals<br>CV3 Row 211 – 33kV Transformer (GM) |
| EHV Transformers asset refurbishment | £4.5m | 1.51.11 | CV5 Row 32 – 33kV Transformer (GM) |
| 132kV Transformers asset replacement | £0.8m | 1.51.01 | CV8 multiple rows |

| | | | |
|---|---|---|---|
| EHV Transformers asset replacement | £1.5m | 1.51.03 | CV8 multiple rows |

*Table 1 – ED1 investment overview*

*Expenditure on this asset type is also included on CV6 Civils

A full list of abbreviations is included in Section 6.0 of Document 20: Capex Opex Overview.

## 1.2 Investment Strategy

The ED1 investment strategy for 132kV and EHV Transformers is detailed in UK Power Networks' Engineering Design Procedure EDP 00-0012, *Asset Lifecycle Strategy – Major Substations*. The investment plan has been developed in accordance with this strategy and by making use of the Asset Risk and Prioritisation (ARP) model to assess all asset data available in order to determine asset health, criticality and consequence of failure. This has enabled the construction of a well-justified plan based on detailed knowledge of individual assets, rather than age or statistical modelling approaches.

The strategy for selecting the level of investment required has been to maintain a constant number of assets with Health Index scores of 4 or 5 from the start of the ED1 period to the end. Overall network risk will increase due to the deterioration of HI1 and HI2 assets as they become HI2 or HI3.

## 1.3 ED1 Proposals

Table 2 shows the planned interventions by asset type during the ED1 period.

Figure 1 and Figure 2 show how the numbers of HI4/HI5 132kV and EHV Transformers are projected to vary across the ED1 period, given the planned interventions.

| | | Intervention volumes | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Asset** | **Intervention** | **15/16** | **16/17** | **17/18** | **18/19** | **19/20** | **20/21** | **21/22** | **22/23** | **ED1 Total** |
| 132kV Transformers | Replacement | 1 | 0 | 0 | 5 | 2 | 1 | 0 | 1 | 10 |
| 132kV Transformers | Refurbishment | 0 | 0 | 0 | 0 | 4 | 1 | 2 | 2 | 9 |
| EHV Transformers | Replacement | 2 | 2 | 6 | 7 | 5 | 2 | 8 | 5 | 37 |
| EHV Transformers | Refurbishment | 3 | 2 | 5 | 2 | 4 | 4 | 6 | 5 | 31 |

*Table 2 – ED1 intervention volumes summary*

Appendix 9 benchmarks our ED1 proposals with reference to other DNOs July 2013 submissions. It shows that for Grid and Primary Transformers we are proposing to replace 7% of our assets while other DNOs were seeking funding to replace 10% of these assets on average. This demonstrates the effectiveness of our asset risk management systems and the value for money of our proposals.

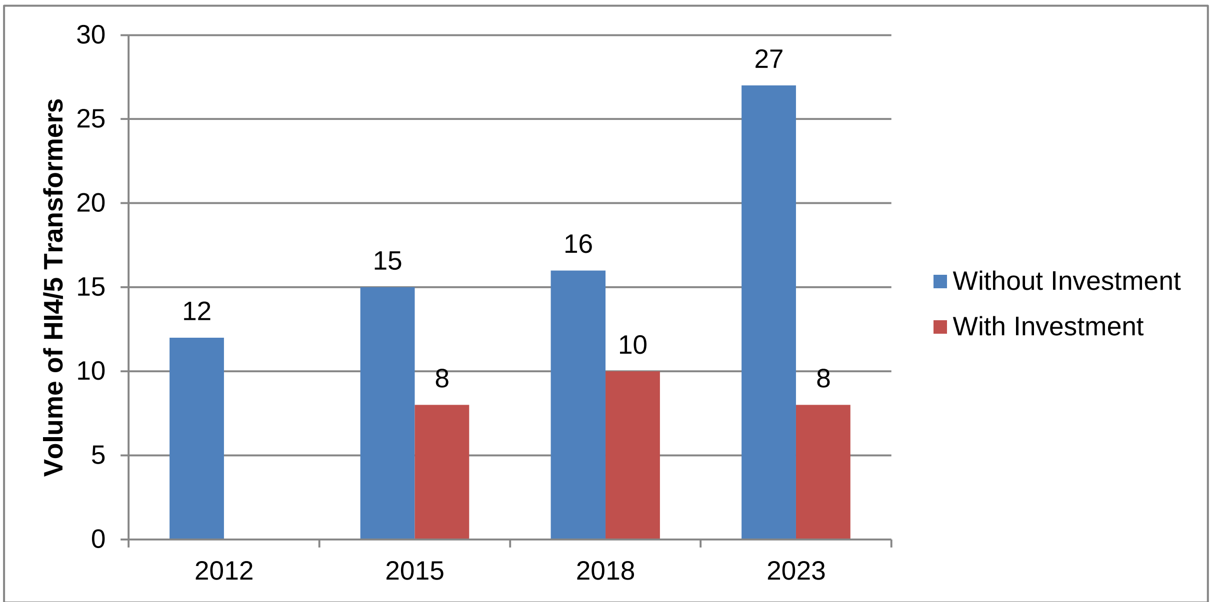



*Figure 1 – Projected 132kV Transformer HI4/HI5 profile*

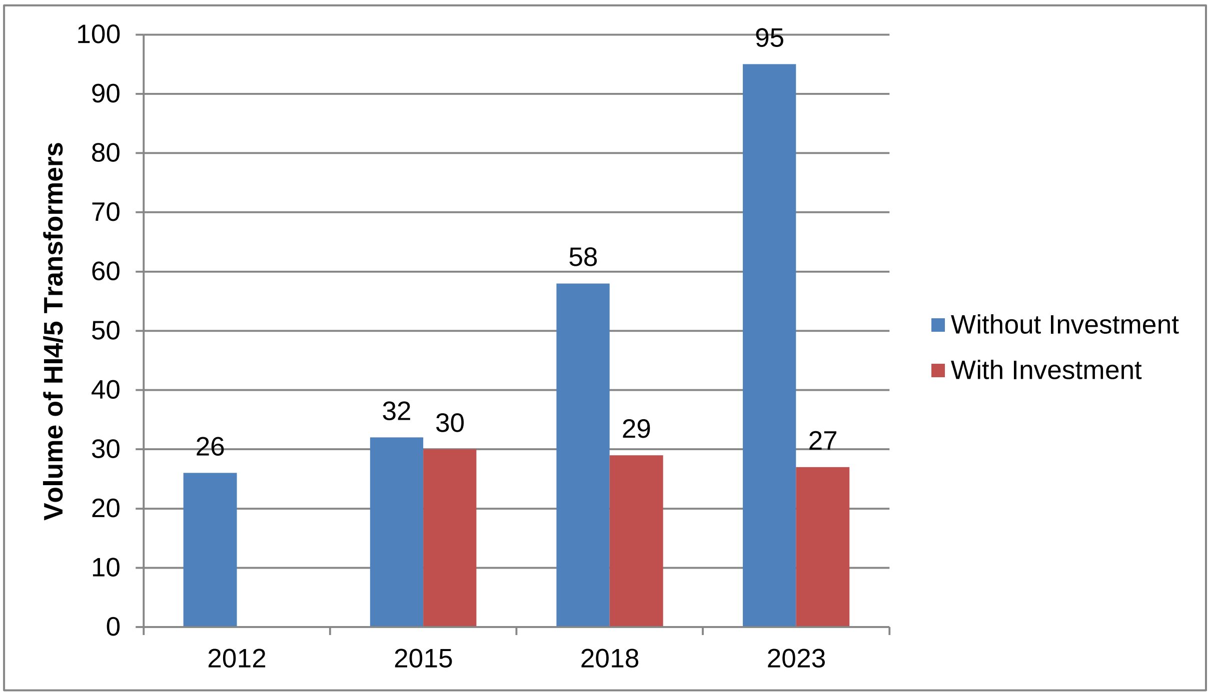



*Figure 2 – Projected EHV Transformer HI4/HI5 profile*

## 1.4 Innovation

A number of refurbishment options have been developed, some of which have been tested during DPCR5. These will allow the replacement of assets to be deferred. In the ED1 investment plan, there are 40 refurbishments that will save £23.8m of costs compared with traditional replacement strategies.

Ongoing research will drive continuous improvement in our asset health determinations, ensuring the maximum serviceable life of assets while managing network risk effectively.

## 1.5 Risks and Opportunities

| | Description of similarly likely opportunities or risks arising in ED1 period | Level of (uncertainties)/ cost growth (£m) |
|---|---|---|
| Opportunity | Use refurbishment options 5% more often than planned | (£1.4m) |
| Risk | Cannot undertake 20% of planned refurbishment | £4.8m |
| Risk | Cost of refurbishment rises by 20% for 20% of planned refurbishment interventions in ED1 period | £0.2m |

*Table 3 – Risks and opportunities*

# 2.0 Description of 132kV and EHV Transformer Population

## 2.1 132kV Transformers

In the SPN licence area, there are 164 transformers with a primary winding voltage of 132kV and ratings ranging from 7.5MVA to 90MVA. Secondary winding voltages are 33kV, 11kV or 6.6kV. These assets are located on 64 substation sites; 47 of these transformers are within 5km of the coast, and so, as defined by the Galvanizers Association, are subject to higher corrosion ratings.

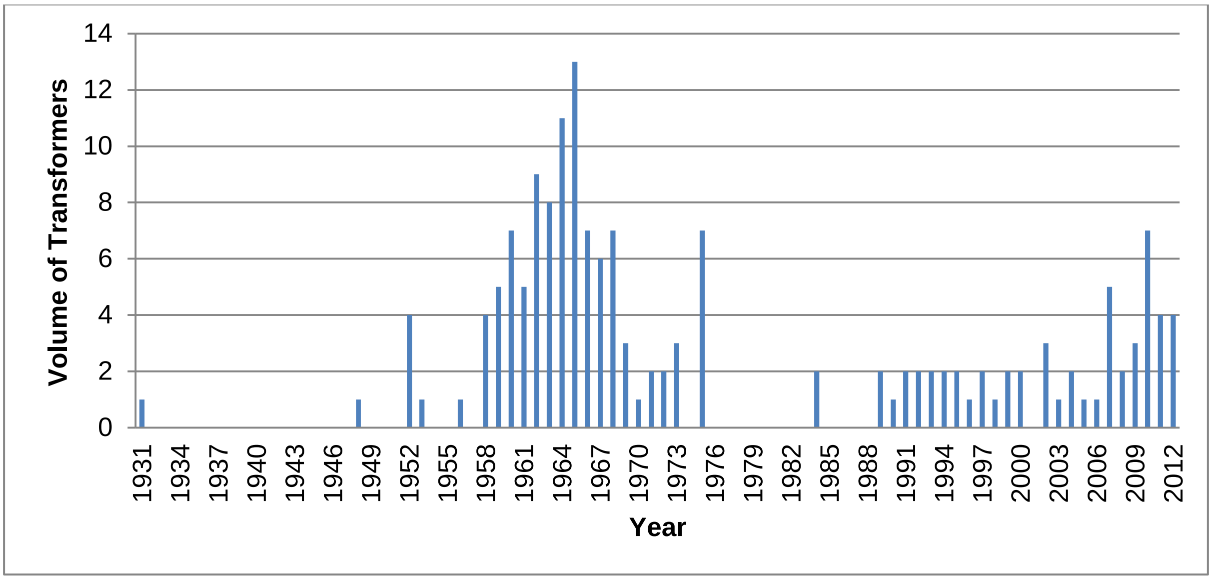



*Figure 3 – SPN 132kV Transformer age profile*

Source: 2012 RIGs V5

As can be seen from the age profile in Figure 3, significant investment was made in the 1950s/60s; the average age of these assets is 35.5 years. The average age of the oldest 10% of 132kV transformers is 58 years.

| NAMP line | Description |
|---|---|
| 1.51.01 | 132kV Transformer replacement |
| 1.51.11 | 132kV and EHV Transformer refurbishment |

*Table 4 – NAMP reference*

| RIGs tab | Line | Asset Category | Activity |
|---|---|---|---|
| CV3 | 101 | 132kV Transformer | Additions |
| CV3 | 229 | 132kV Transformer | Removals |
| CV5 | 52 | 132kV Transformer | Refurbishment - Transformer |

*Table 5 – RIGs reference*

## 2.2 EHV Transformers

In the SPN licence area, there are 473 EHV Transformers with a primary winding voltage of 33kV and ratings ranging from 3MVA to 30MVA. Secondary winding voltages are 11kV, 6.6kV or 3.3kV. These assets are located on 234 substation sites; 140 of these transformers are within 5km of the coast, and so, as defined by the Galvanizers Association, are subject to higher corrosion ratings.

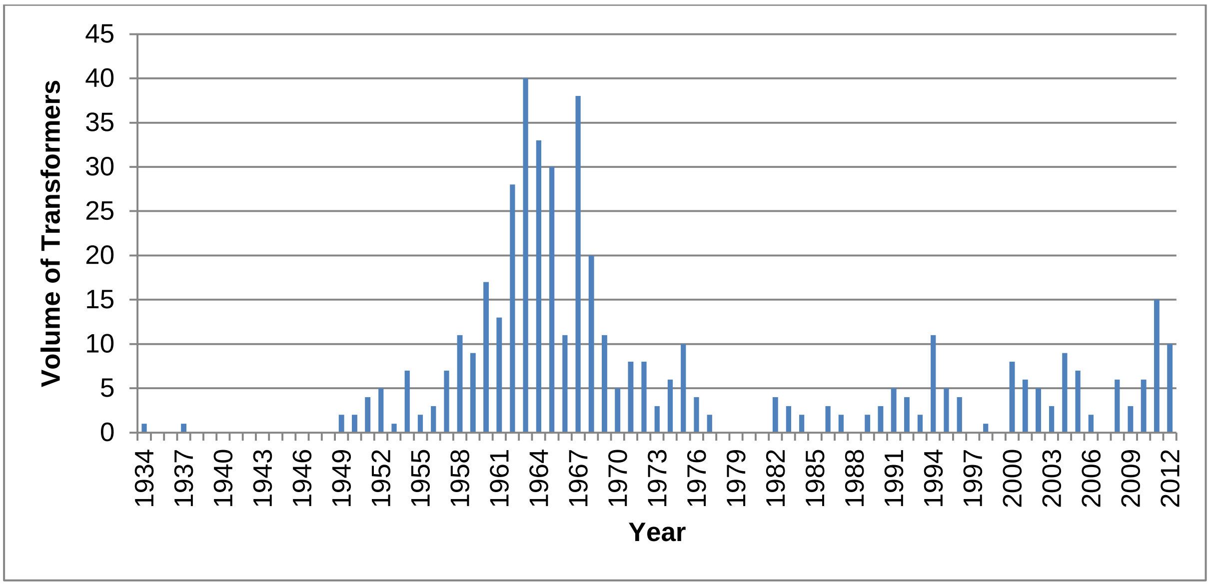



*Figure 4 – SPN EHV Transformer age profile*

Source: 2012 RIGs V5

As can be seen from the age profile in Figure 4, significant investment was made in the 1960s; the average age of these assets is 37.5 years. The average age of the oldest 10% of EHV Transformers is 58 years.

| NAMP line | Description |
|---|---|
| 1.51.03 | EHV Transformer replacement |
| 1.51.11 | 132kV and EHV Transformer refurbishment |

*Table 6 – NAMP reference*

| RIGs tab | Line | Asset Category | Activity |
|---|---|---|---|
| CV3 | 83 | 33kV Transformer (GM) | Additions |
| CV3 | 211 | 33kV Transformer (GM) | Removals |
| CV5 | 32 | 33kV Transformer (GM) | Refurbishment - Transformer |

*Table 7 – RIGs reference*

# 3.0 Investment Drivers

## 3.1 Condition Measures

### 3.1.1 Transformers

Investment drivers from the transformer can be split into two categories: internal condition and external condition. External condition factors include paint condition and corrosion of any part of the transformer, cooler or conservator, and their pipe work. In addition, old gasket material can become compressed and brittle.

*Figure 5 – Severe oil leak from main cover gasket, Chessington Grid GT2*

These factors pose both an environmental risk, particularly on older transformers without oil bunds, and a network risk, as they can lead to severe oil leaks and unplanned outages. UK Power Networks' Health, Safety and Sustainability Standard HSS 01 021, *Environmental Management of Insulating Oils: Use, Handling, Storage, Recording and Disposal*, requires transformers with persistent oil leaks to be considered for repair or replacement. Internal condition factors are the degradation of solid insulation materials on the windings and the development of discharge and heating faults. Both of these internal condition factors are detected by non-intrusive oil sample testing.

### 3.1.2 Tap changers

As tap changers are the only moving part of the transformer, they are the most maintenance-intensive part and so often the most likely to develop defects. Although the assessment of external condition is the same as for the transformer, regular maintenance means that the internal condition can be assessed more easily.

Tap changers regularly have contacts changed, but older models increasingly require additional parts, such as new springs, due to the originals becoming weak over time. With many old tap changers, obsolescence becomes an issue, as there is no manufacturer support, which makes it difficult to obtain the necessary parts (an example is the Allenwest LS slow-speed tap changers manufactured from the early 1950s). This increases the operational expenditure, as parts are manufactured to order, often without the original designs available, so there is a reliance on recovering parts from decommissioned units. In total there are 41 different tap changer designs commissioned in SPN.

## 3.2 Defects

Defects are an important way of recording non-conformities that could affect the performance of assets and impact their health. Table 8 shows the defects on transformer, tap changer and cooler assets that affect an asset's health and are reportable within our asset register, Ellipse. Each defect is assigned a priority rating, as defined in Table 9. This sets the target timescale for repair.

| Defect description | Defect priority |
|---|---|
| Compound Leak | P2 |
| Defect Breather | P1 |
| Defect Bushing | P4 |
| Defect Control/Marshalling Cubicle | P3 |
| Defect Cooler Auto Control | P4 |
| Defect Cooler Fail Alarm | P4 |
| Defect Cooler Fan | P4 |
| Defect Cooler Oil Pump | P4 |
| Defect Cooler Water Pump | P4 |
| Defect Drycol Unit | P1 |
| Defect Oil Level Low or High | P5 |
| Defect Tapchanger Operation | P5 |
| Defective Cable Box | P2 |
| Plant Subsidence | P2 |
| Tapchange counter malfunctioning | P2 |

*Table 8 – Transformer, tap changer and cooler defects*

| Defect criticality | Defect criticality definition |
|---|---|
| P1 | At next maintenance |
| P2 | <4 years |
| P3 | <2 years |
| P4 | <1 year |

| | |
|---|---|
| P5 | <3 months |

*Table 9 – Defect criticality*

### 3.2.1 Compound Leak and Defect Cable Box

Bitumen compound or G38 oil is used as an insulation medium in cable boxes on older transformers. If any of the insulant leaks out, the impulse rating is reduced, increasing the risk of disruptive failure if the equipment is subject to an overvoltage. Defective Cable Box is used to record where thermal imaging surveys identify an abnormal rise in temperature.

### 3.2.2 Defect Breather/Defect Drycol Unit

These indicate defects with the passive/active breathers on transformers or tap changers. Defective breathers can lead to moist air coming in contact with the oil, increasing the water content of the oil and papers in the transformer.

### 3.2.3 Defect Bushing

This is used to record damaged bushings or oil filled bushings with severe oil leaks. It is applicable to both HV and LV transformer bushings.

### 3.2.4 Defect Control/Marshalling Cubicle

This is a means of recording defects in the small wiring, auxiliary fuses and terminal blocks associated with the control of the transformer and tap changer. These defects can prevent the correct operation of the AVC and transformer and tap changer alarms.

### 3.2.5 Cooler Defects

Defect Cooler Auto Control, Fail Alarm, Fan, Oil Pump and Water Pump all refer to defects with the transformer forced cooling system. Any defects in these systems can affect the rating of the transformer, resulting in overstressing of the asset.

### 3.2.6 Defect Oil Level Low or High

During inspection, the oil sight glasses are checked to ensure the oil level is correct. Low oil level can indicate leaks and is a risk to network security, particularly during cold weather. If the oil level drops too low, it will result in a Buchholz alarm or trip, affecting network security and incurring extra operational expenditure.

### 3.2.7 Defect Tapchanger Operation/counter malfunctioning

This is used to record tap changers that are not in an operational state for any reason, such as the AVC scheme malfunctioning or a broken mechanism identified during maintenance. This is classed as a P5 defect due to the impact a non-operational tap changer has on the voltage regulation. A malfunctioning counter can make it harder to identify where abnormal tapping operations are occurring, limiting the ability to detect a potential problem early.

### 3.2.8 Plant Subsidence

This identifies where subsidence is or will affect the operation of an asset.

### 3.2.9 Defect analysis

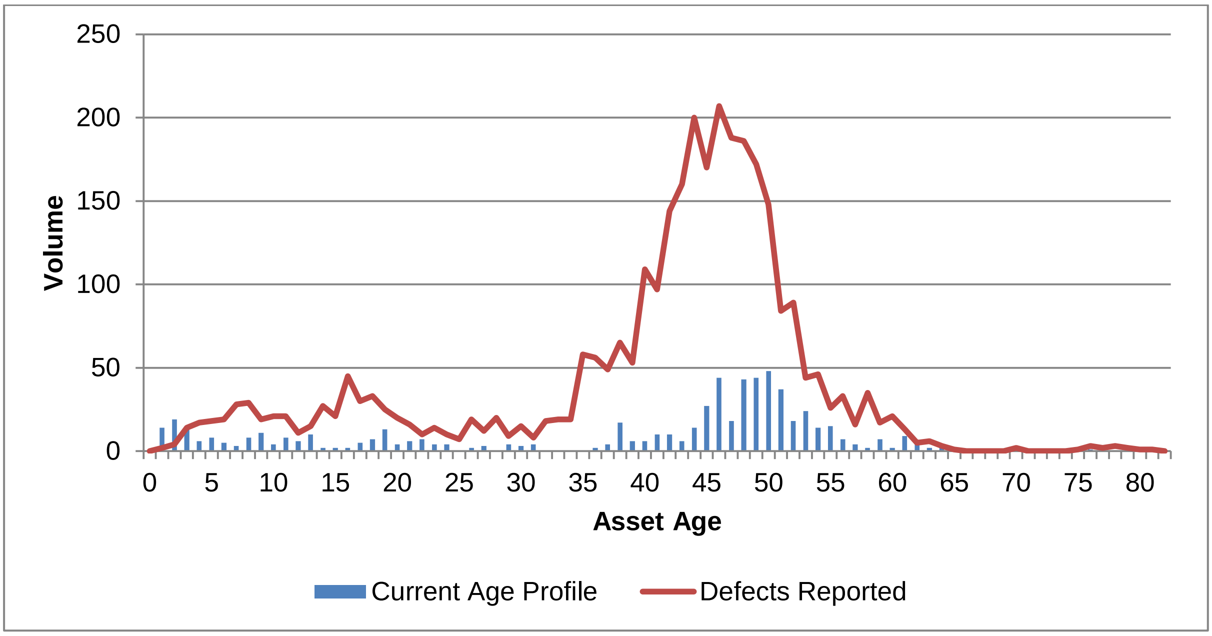



*Figure 6 – SPN 132kV and EHV Transformer defect rate*

Sources: Ellipse Extract 19/02/2013
2012 RIGs V5

Figure 6 shows the number of defects recorded in Ellipse on transformers, tap changers and coolers versus the age of the asset at the time the defect was reported, superimposed on the current combined age profile of 132kV and EHV Transformers in SPN. The number of defects increases with asset age; significant numbers of defects are reported on transformers in the 40–55-year age bracket. This age bracket corresponds with the Average Asset Life, as used in the HI modelling tool (see section 4.1.1 for more information). This rate of defects poses significant risk to the network and requires continued operational expenditure to remedy. ED1/ED2 capital investment will manage this risk as this age group of transformers moves towards end-of-life.

## 3.3 Fault Rate

Figure 7 and Figure 8 show that fault rates of 132kV transformers have increased since DPCR4, while fault rates for EHV Transformers have remained stable. The replacement and refurbishment programmes will address the defects that lead to these faults and stabilise the fault rate going in to ED2.

The fault data has been split into two categories: condition and non-condition faults. Non-condition faults relate to any fault not caused by the asset itself, such as third-party damage, bird strikes or weather. Examples of condition faults are bushing faults, wear and tear of the tap changer mechanism and loss of oil due to severe corrosion.

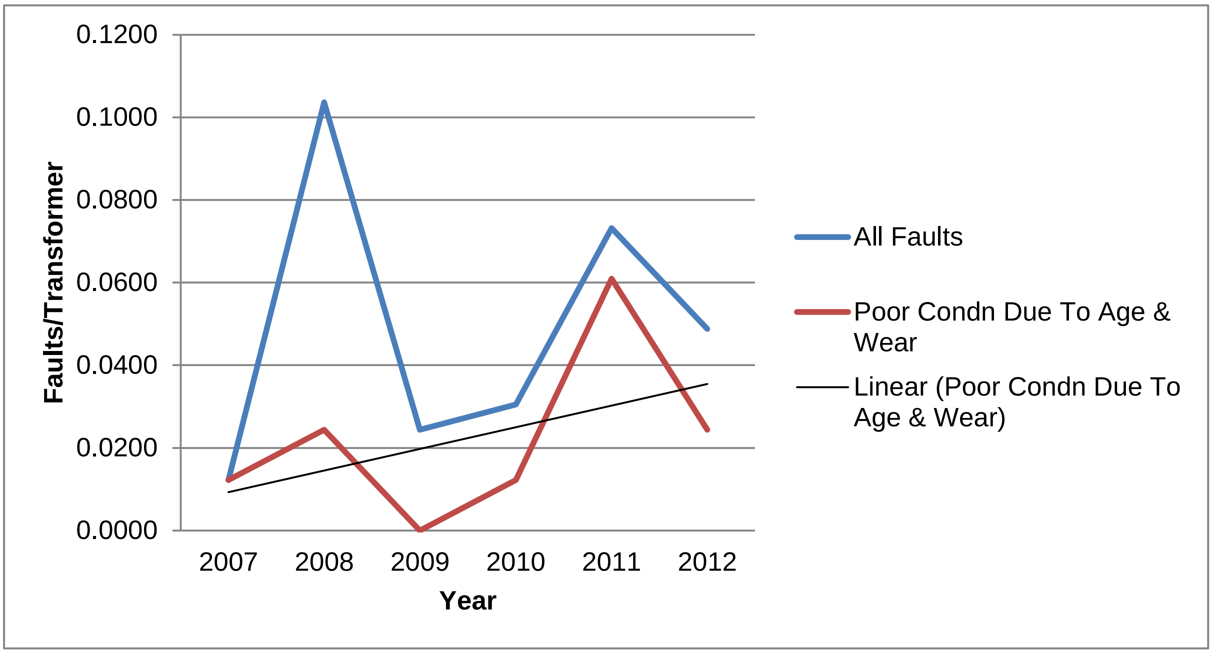



*Figure 7 – 132kV Transformer fault rate*

Source: UK Power Networks Fault Analysis Cube

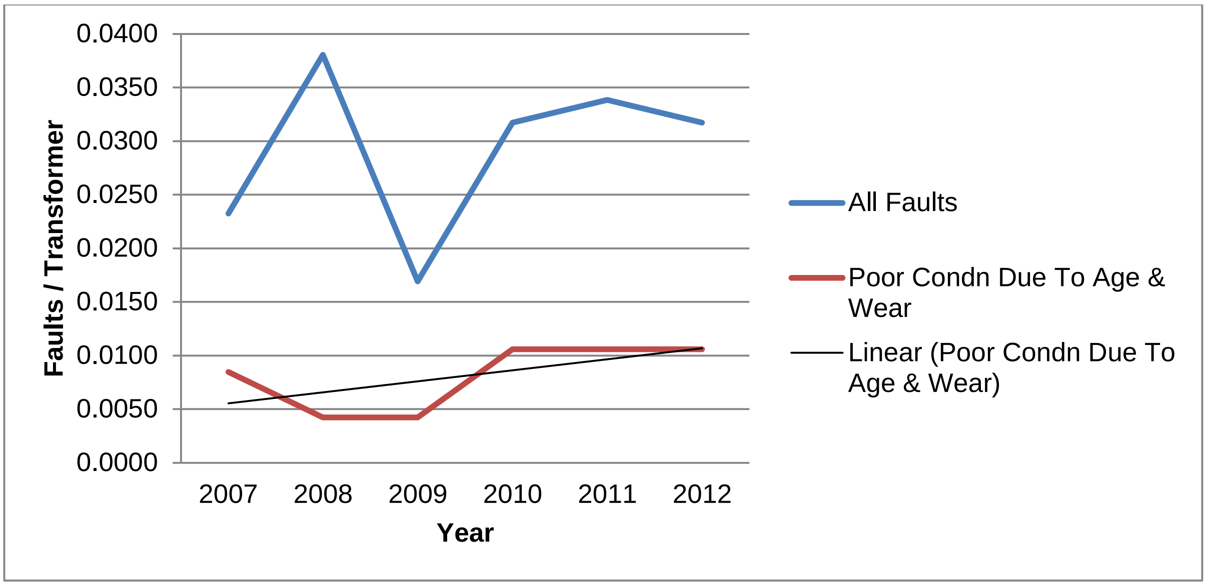



*Figure 8 – EHV Transformer fault rate*

Source: UK Power Networks Fault Analysis Cube

## 3.4 Asset Age

Although asset age is not a primary investment driver for the 132kV and EHV Transformer expenditure plans, it does have a cumulative effect on the serviceability of some of these assets. Table 10 shows how the proportion of the population of 132kV and EHV Transformers above the average asset life of 50 years for 132kV Transformers and 51 years for EHV Transformers will increase dramatically from 2015 to 2023 without investment. Refer to section 4.1.1 for more information on Average Asset Life.

| | Transformer population | Transformers over average asset life in 2015 | % Transformers over average asset life in 2015 | Transformers over average asset life in 2023 | % Transformers over average asset life in 2023 |
|---|---|---|---|---|---|
| 132kV Transformers | 164 | 49 | 30% | 94 | 57% |
| EHV Transformers | 473 | 146 | 31% | 309 | 66% |

*Table 10 – Asset age vs. average asset life*

Sources: 2012 RIGs V5
ARP Model LW_TX_25Jul2012

Reliability is linked to asset age and there is a risk to network operation from increasing numbers of defects and faults. As can be seen from Figure 7 and Figure 8, fault rates for these assets are rising on average but are changeable on a year to year basis. The small population of assets and low fault rates make it difficult to forecast fault rates through ED1 and ED2. If the fault rates continue to increase this is likely to increase customer interruptions and, if not addressed during ED1, would leave a large investment requirement for ED2 that could not be delivered as there is insufficient network capacity to accommodate the number of outages that such a construction project requires.

## 3.5 Condition Measurements

In order to determine the levels of interventions required in an intelligent way, to provide the best possible value-for-money solution for customers, it is necessary to accurately assess the health of the assets rather than use an age-based approach. To assess the health, it is essential to have the right data available and to ensure it is of a high quality.

### 3.5.1 Substation inspection

The main source of asset external condition data is from Substation Inspectors. In order to improve condition data quality, during the first half of DPCR5 a review of the *Substation Inspectors' Handbook* was carried out and a new handbook was issued. All inspectors were required to undertake a two-day training course and pass the theory and practical examinations before being certified as competent inspectors.


*Figure 9 – Handheld device used in inspections and maintenance*

Handheld devices (HHD) are increasingly being used on site at the point of inspection in order to ensure good quality and timely data is captured and recorded in the asset register. When an inspection HHD script is run, the user answers a set of questions specific to each asset type, about the asset's condition; this allows defects to be recorded, reviewed and cleared. This method of inspection, together with in-depth training, ensures that condition and defect assessments are carried out objectively, thereby giving consistent results from inspector to inspector across the business.

UK Power Networks' Engineering Maintenance Standard EMS 10-0002, *Inspection and Maintenance Frequency Schedule*, specifies that all 132kV and EHV Transformers be inspected at least every six months.

### 3.5.2 Maintenance

Maintenance fitters also use the same HHD technology to record their assessment of the internal and external condition of the assets being maintained. This assessment is made twice during each maintenance task, to provide condition data "as found" and "as left".

One key assessment of a transformer's external condition, particularly on older transformers, is the degree of oil leaks. In addition to the substation inspectors' scoring of oil containment, maintenance teams record the volume of oil in litres whenever they top up the oil level. This allows leakage rates to be measured for each transformer.

UK Power Networks' Engineering Maintenance Standard EMS 10-0002, *Inspection and Maintenance Frequency Schedule*, requires that all 132kV and EHV Transformers be maintained every eight years. Tap changers have various maintenance cycles that are dependent upon the make and model. High-speed tap changers are maintained less frequently than older slow-speed tap changers, and some models have known issues or a history of defects that require them to be maintained as often as every two years. An example is the English Electric FDB tap changer, which has a history of hairline cracking on the phase barrier mouldings, which requires regular inspection.

### 3.5.3 Oil analysis

Oil samples are taken regularly from all grid and primary transformers to assess their internal condition. By measuring the furans (FFA) in the oil, the degree of polymerisation of the paper on the windings can be interpolated to give an estimate of the paper's remaining life. Dissolved Gas Analysis (DGA) is also carried out to identify developing faults within the transformer. The dissolved gases are produced in the oil when heating processes such as discharge or arcing are taking place. By assessing the trend of gases, a developing fault can be identified and addressed.

UK Power Networks' Engineering Maintenance Standard EMS 10-0002, *Inspection and Maintenance Frequency Schedule*, specifies that all 132kV and 66kV transformers are sampled annually and all other EHV Transformers are sampled every four years. Samples are sent to one of two external laboratories for independent analysis.

Figure 10 shows the FFA results for T2 at Brighton Town 33/11kV substation. Interpretation of oil analysis results are not just reliant on an individual, high reading but involves looking for changes in a particular asset's normal measurements. This transformer has seen a steady increase in FFA since 1997 and is now at a high level. FFA levels considered to correspond to an HI4 and HI5 have been included on the graph for reference.

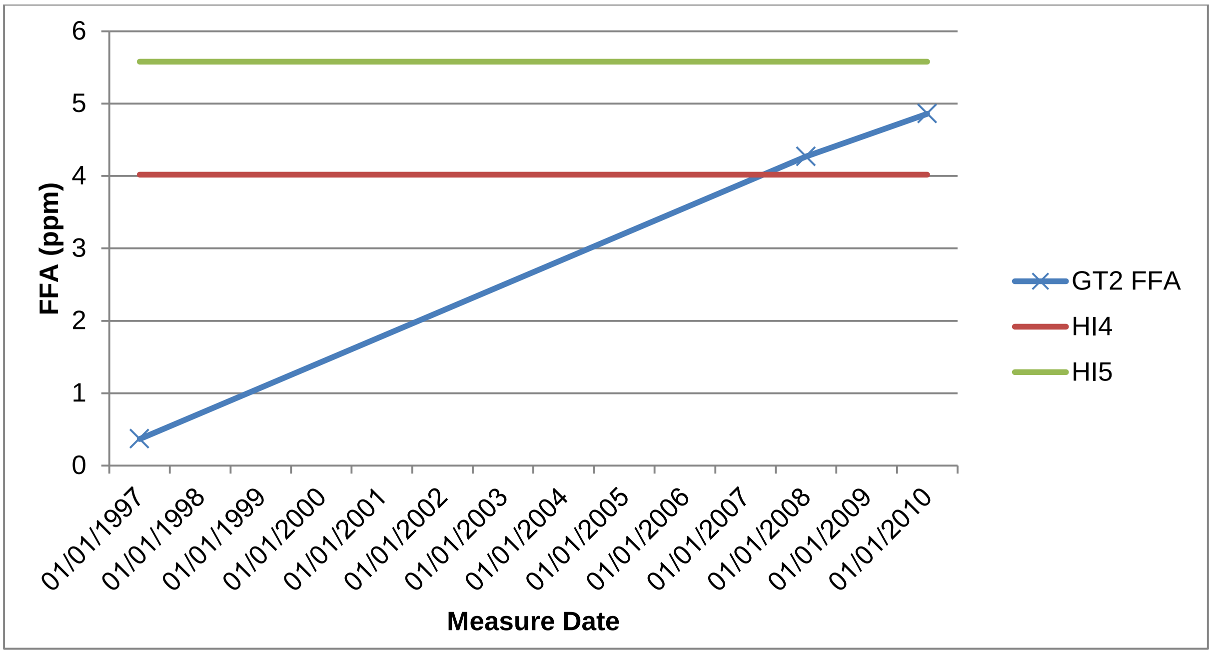



*Figure 10 – Increasing FFA, Brighton Town T2*

Source: Ellipse Extract 01/03/2013

One challenge with DGA is identifying spurious results. It is possible for the oil in the main tank of the transformer to be contaminated with gases produced in a common tank tap changer or separate diverter. This contamination can be the result of shared oil, leakage through the barrier board or shared headspace above the surface of the oil in a transformer/tap changer conservator. Where this problem has been identified, the asset health has been recalculated to ensure the asset is not included in the ED1 plan without further justification; this has been implemented for 28 transformers in SPN and has identified ATL AT tap changers as being particularly prone to contaminating main tank oil. Identifying these spurious results and recalculating the health of the transformer provides savings for our customers because there is no need to make unnecessary allowances.

# 4.0 Asset Assessment

## 4.1 Asset Health

An innovative asset-health modelling tool has been developed for several asset categories, including grid and primary transformers. The methodology behind the modelling is the same for all asset categories, but the transformer model has been tailored specifically to use the data collected to assess against the identified investment drivers for transformers.

Further information is available in *Commentary Document 15: Model Overview*, which details the methodology and asset data required to calculate an initial Health Index (HI) for each asset. Figure 11 shows the process from inputting data to calculating the current and future health indices for 132kV and EHV Transformers.

Condition scores recorded during inspection and maintenance and oil top-up history are then used to calculate a weighting factor that is applied to the initial HI. A similar process is also used to calculate a weighted HI for the tap changer. Separate HI scores are calculated for DGA, FFA and oil quality using oil sample results, excluding any data more than 10 years old. The highest score from these contributing HIs is identified as the main HI driver and is used as the overall HI score for each transformer.

As transformer oil leaks can have significant environmental, network and business consequences, it is our policy, as stated in UK Power Networks' Health, Safety and Sustainability Standard HSS 01-021, *Environmental Management of Insulating Oils: Use, Handling, Storage, Recording and Disposal*, to ensure all topping up of oil is recorded in the asset register. This ensures that leaking transformers can be identified and the appropriate course of action is planned in a timely manner. Where the Oil Containment condition measure is recorded as a 4 (on a 1–4 scale), the overall HI of the transformer cannot be less than 4.

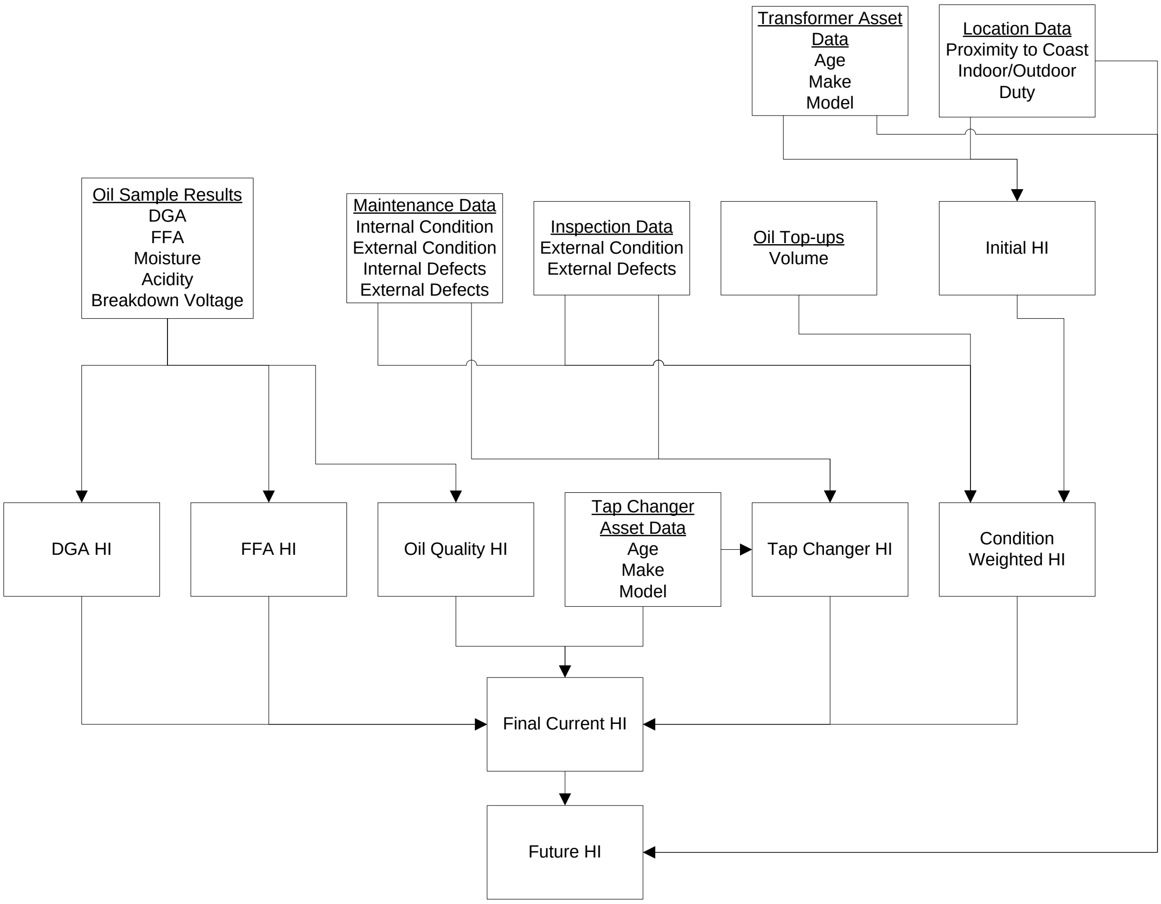



*Figure 11 – Transformer HI modelling methodology*

### 4.1.1 Average Asset Life

In order to calculate asset health degradation, each asset is assigned an Average Asset Life in the ARP model. This is defined in the model calibration and is specific to the manufacturer and model of the asset. This approach takes into account the changes in transformer design and manufacturing processes over time. In this context, within the ARP model, the Average Asset Life is considered to be the point in the life of the asset when significant increases in defects start to appear and it is found to be in poorer condition.

**Note:** The majority of transformers will remain in service significantly beyond their assigned Average Asset Life in the ARP model. For further details and examples of average asset lives for these assets, refer to *Commentary Document 15: Model Overview*.

## 4.2 Asset Criticality

Another feature of the ARP model still under development can be used to calculate the criticality of a particular transformer asset. This is then defined in the form of a Criticality Index with a scale of 1 to 4, with 1 being the least critical and 4 being the most critical. A detailed methodology for calculating the Criticality Index can be found in *Commentary Document 15: Model Overview*.

Five main areas are considered when calculating the criticality of assets: network performance, safety, operational expenditure, capital expenditure and the environment. A number of factors generic to all ARP models are used in these areas, in addition to some specific to transformers.

For network performance, the key factors for the transformer model are the number of customers that the substation feeds and the maximum substation demand.

The safety criticality is assessed on the ESQC risk rating for the site and the situation of the transformer (indoor, outdoor or basement).

The operational and capital expenditure criticalities consider the assets in terms of the ease of carrying out works due to the equipment situation and site type and also the transformer rating.

Finally, the environment section considers whether the site is in an environmentally sensitive location and if the transformer is housed in a bunded area.

## 4.3 Network Risk

ARP allows for an innovative new approach to calculating network risk for a given asset category. UK Power Networks believes this is one of the first comprehensive applications of such quantified risk modelling for electricity distribution networks worldwide. The network risk is determined by the probability of failure, directly proportional to the HI, and the criticality of each asset. The consequence of failure is the average cost to repair or replace a transformer following one of three failure modes. This section of the ARP model is still in the early stages of development.

| Failure mode | Description |
|---|---|
| Minor | Can be repaired by maintenance teams |
| Significant | Can be repaired using external resources/expertise |
| Major | Cannot be repaired on site; offsite repair or replacement is required |

*Table 11 – Failure mode definitions*

Section 7.6.2 details the method of this risk analysis and the results obtained.

## 4.4 Data Validation

All data used in the ARP model is subject to validation against a set of data requirements. The requirements ensure data is within specified limits, up to date and in the correct format for use in the model. On completion of the validation process, an exception report is issued. This provides details of every non-compliance and supports the continual improvement of data quality.

One measure used in the ARP model, Moisture Corrected to 20°C, has a valid range of 0 to 100ppm, with any data outside this range being excluded from the model and leading to the creation of an exception report. In addition, oil sample data more than 10 years old is excluded from the model.

## 4.5 Data Completeness

As the asset condition data, particularly oil sample results, is such a vital part of determining the health of a transformer, the data was tested for completeness. In order for a particular set of oil sample results to be considered complete, certain measures had to be identified as ‘essential’; moisture, acidity, FFA, hydrogen, methane, ethane, ethylene and acetylene. To be able to establish trends while ensuring data is not obsolete, oil sample results older than 10 years old are excluded from the ARP model.

Table 12 shows the number of oil sample result sets, distinct transformers with at least one set of oil sample results and distinct transformers with at least one set of oil sample results with all ‘essential’ measures, also expressed as a percentage of the asset population.

| | 132kV Transformers | EHV Transformers |
|---|---|---|
| Total number of oil sample records | 911 | 1,094 |
| Number of records with essential measures populated | 818 | 926 |
| % records with essential measures populated | 90% | 85% |
| Number of distinct transformers with oil sample records | 161 | 468 |
| % distinct transformers with oil sample records | 98% | 98% |
| Number of distinct transformers with essential measures populated | 161 | 450 |
| % distinct transformers with essential measures populated | 98% | 94% |

*Table 12 – SPN oil sample data completeness*

Source: Ellipse Extract 28/01/2013

The completeness, accuracy and timeliness of all the data, including oil sample results, used in the ARP model are routinely checked. The latest results are shown in Table 13.

| Area | Result |
|---|---|
| Completeness | 90% |
| Accuracy | 89% |
| Timeliness | 99% |

*Table 13 – ARP SPN data CAT scores*

Source: Ellipse Extract 27/11/2012

These results provide confidence in our key condition data, which has allowed us to better manage risk and build a well-justified plan for ED1.

## 4.6 Model Testing

The ARP model was subject to rigorous testing to ensure it met the defined requirements prior to acceptance. There were four distinct subsets to the testing process: algorithm testing, software testing, data flow testing and user and methodology testing. Each test was designed to capture potential errors in specific parts of the system. The completion of all tests provided assurance that a thorough evaluation has been carried out to ensure correctness and validity of the outputs.

### 4.6.1 Algorithm testing

The ARP model comprises a set of algorithms implemented within the database code. The tester, in a spreadsheet, mimicked each algorithm comparing the results with those of the ARP algorithm for a given set of test data inputs. The test data comprised data within normal expected ranges, low-value numbers, high-value numbers, floating point numbers, integers, negative numbers and unpopulated values. In order to pass the test, all results from the ARP algorithm were required to match the spreadsheet calculation.

### 4.6.2 Software testing

A number of new software functions used in the model required testing to ensure they performed correctly. A test script was created to identify the functional requirement, the method to carry out the function and the expected outcome. In order to pass the test, the achieved outcome had to match the expected outcome.

### 4.6.3 Data flow testing

Data flow testing was carried out to ensure that data presented in the ARP upload files passes into the model correctly. Data counts from the ARP model upload files were compared to data successfully uploaded to the model. To pass the test, counts of the data had to match within specified tolerances.

#### 4.6.4 User and methodology testing

The aim of the user and methodology testing was to ensure that the models are fit for purpose. A test script was created to check that displays operate correctly and that outputs respond appropriately to changes in calibration settings.

## 4.7 HI Profile

Figure 12 and Figure 13 show the projected HI profile at the end of DPCR5, including the impact of planned investments in years 4 and 5 of DPCR5.

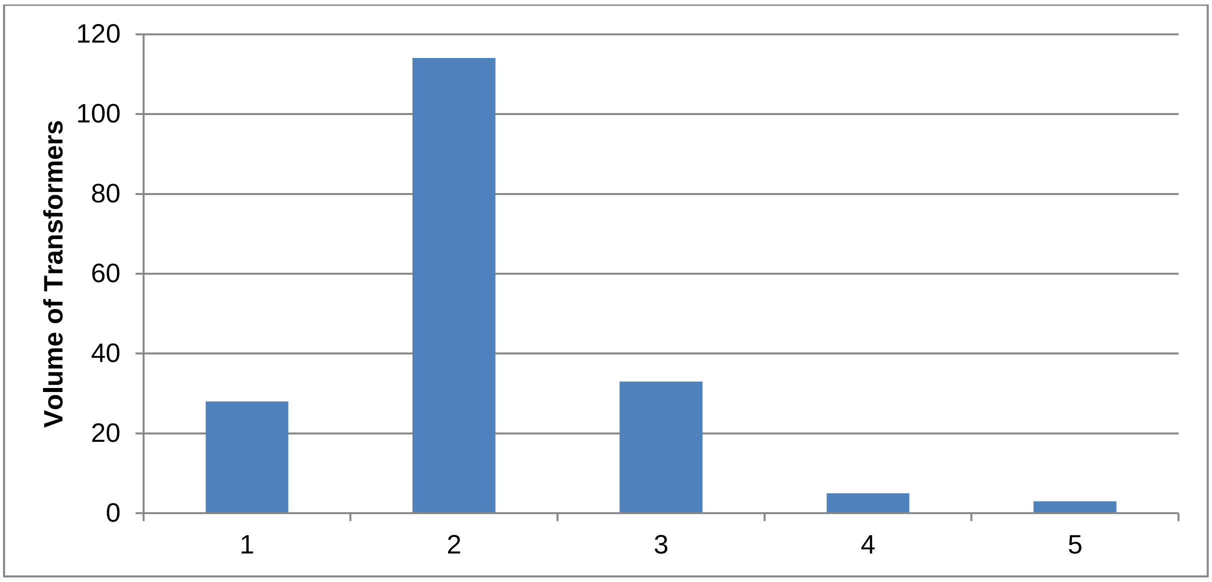



*Figure 12 – Projected 2015 132kV Transformer HI profile*

Source: ARP Model LW_TX_Jul2012

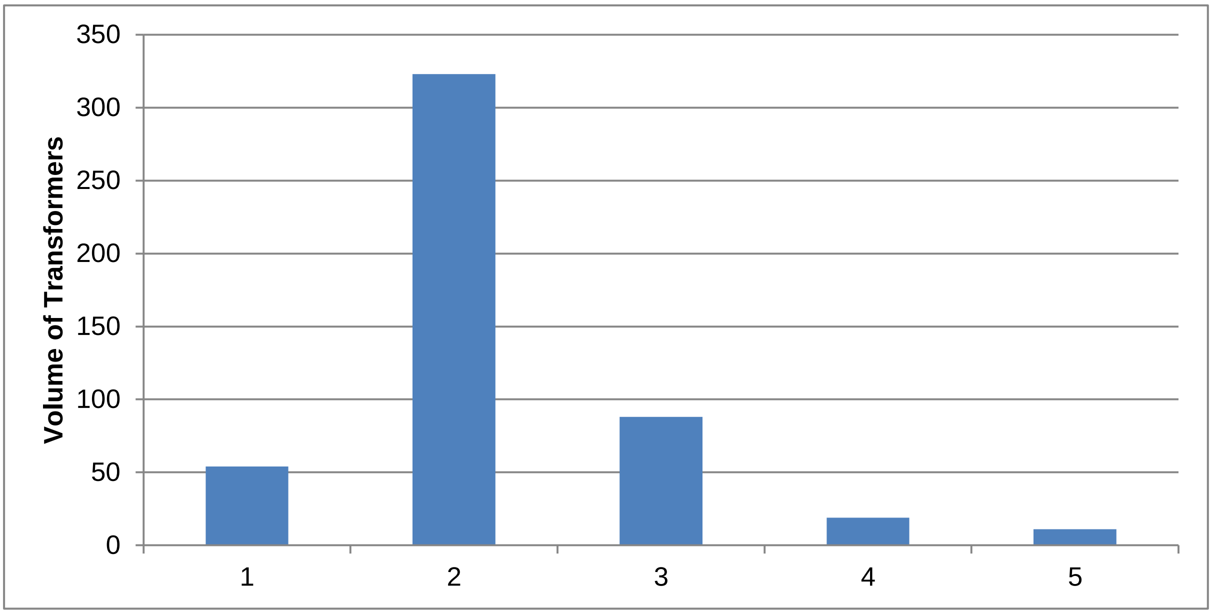



*Figure 13 – Projected 2015 EHV Transformer HI profile*

Source: ARP Model LW_TX_Jul2012

# 5.0 Intervention Policies

## 5.1 Interventions: Description of Intervention Options

In order to maximise the value in ED1 and contain network risk at the lowest cost, a significant and innovative programme of transformer refurbishments is proposed in ED1, in addition to the replacement programme. Refurbishment can be broken down into a range of options, summarised in Table 14, which will be driven specifically by the individual transformer's requirements as defined in UK Power Networks' Engineering Design Standard EDS 04-0006 *132kV and EHV Transformer Non-Load Related Refurbishment and Replacement*.

The chosen refurbishment options, which align to the Ofgem scope of transformer refurbishment work, will target specific problems with each transformer, while returning the transformer to HI2 to achieve a life extension of at least 15 years.

| Transformer refurbishment | |
|---|---|
| **Intervention** | **Description** |
| Gasket replacement | Replacement of old gasket material to cure oil leaks |
| Transformer bushing replacement | Replacement of damaged bushings or to cure severe oil leaks |
| Tap changer refurbishment | Replacement of tap changer mechanism |
| Oil treatment | Treatment to reduce moisture and acidity to extend the life of windings |
| Tap changer replacement | Replacement of obsolete tap changers or where a type defect has been identified |
| Cooler replacement | Replacement of radiator, with consideration for fans, pumps and cooler control systems |
| Conservator replacement | Replacement due to corrosion |
| AVC replacement | New AVC scheme |
| Full factory refurbishment | May include replacement of core and windings |

*Table 14 – Transformer refurbishment options*

## 5.2 Policies: Preferred Interventions

### 5.2.1 Selecting interventions

The ARP model is used to identify the preferred intervention for each asset using the method shown in Figure 14. The key drivers behind the HI score of 4 or 5 are identified, allowing the most appropriate interventions to be selected on an engineering and cost-benefit basis.

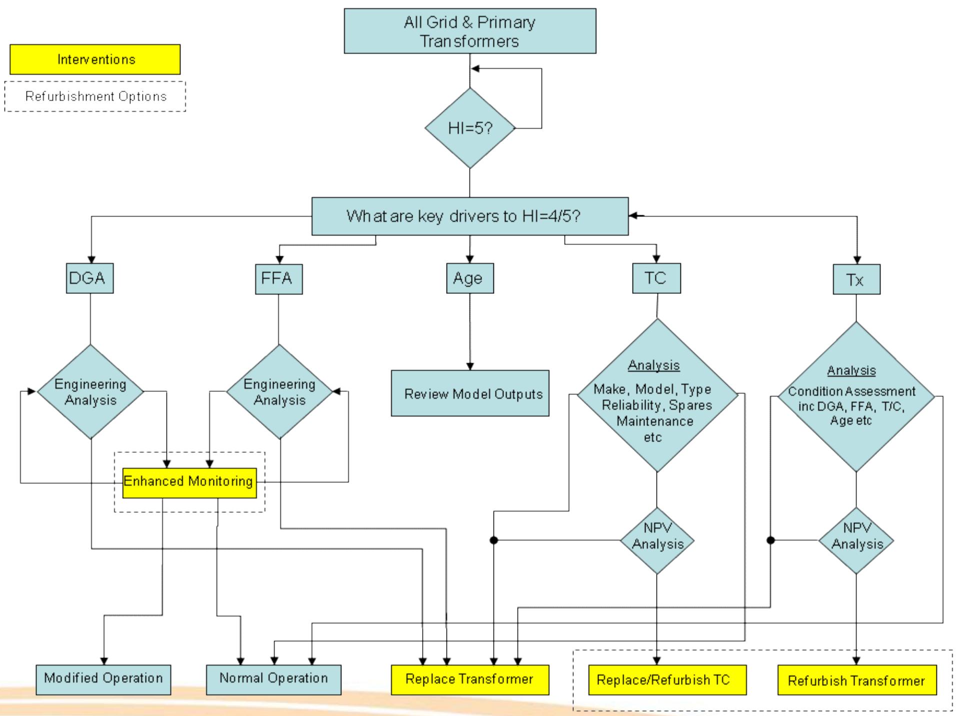



*Figure 14: Intervention Strategy Process*

### 5.2.2 Benefits of refurbishment

By implementing this programme of transformer refurbishments, we will be able to manage the deterioration of the transformers, addressing failure modes that would, if left untreated, result in asset replacement. This will extend the lives of these transformers, reduce whole-life costs and improve reliability and network risk, while minimising short-term expenditure and improving our service to customers. An example *Whole-Life Costs* case study comparing replacement and refurbishment options can be found in Appendix 4.

### 5.2.3 Operational expenditure

This capital expenditure programme, in terms of both replacement and refurbishment interventions, will provide significant benefits to our operational expenditure. Slow-speed tap changers have increased maintenance frequency and are likely to be less reliable and require more defect repairs. By replacing the transformer or the tap changer, as part of a refurbishment, the number of maintenance requirements will reduce.

Also, refurbishing a transformer with severe oil leaks will eliminate the need for both regular oil top-ups and environmental clean-up operations as a result of the leaks.

# 6.0 Innovation

UK Power Networks is actively involved in a number of innovative ways to manage the 132kV and EHV Transformer fleet in addition to the industry-leading health and criticality modelling currently in use. A trial is under way using a failed EHV transformer from Gorringe Park Primary in LPN to assess the benefits of the 're-manufacture' of transformers: the removal of the asset back to the manufacturer for complete refurbishment, including replacement of the core, windings and tap changer. This option can minimise project costs by limiting the cabling and civil works associated with a full transformer replacement. This could be beneficial, particularly where we have a high number of transformers of the same design, because the initial design cost and time would be limited to the first order.

Another trial, to begin shortly, is on the use of advanced transformer cooler control. This system can initiate forced cooling systems based on transformer load, anticipating and limiting a rise in temperature that could increase the rate of ageing of the transformer. It will also monitor the forced cooling system, sending alarms if any failure occurs, enabling Control Engineers to take proactive action to prevent damage to the transformer caused by overloading.

UK Power Networks is also involved in research into areas such as the ageing of transformer insulation, partial discharge diagnostic of transformer insulating fluids, DGA measurement/data interpretation and thermal analysis of transformer insulation systems. More information can be found in the *Innovation Strategy* document.

# 7.0 ED1 Expenditure Requirements for 132kV/EHV Transformers

## 7.1 Method

Figure 15 shows an overview of the method used to construct the ED1 NLRE investment plans.

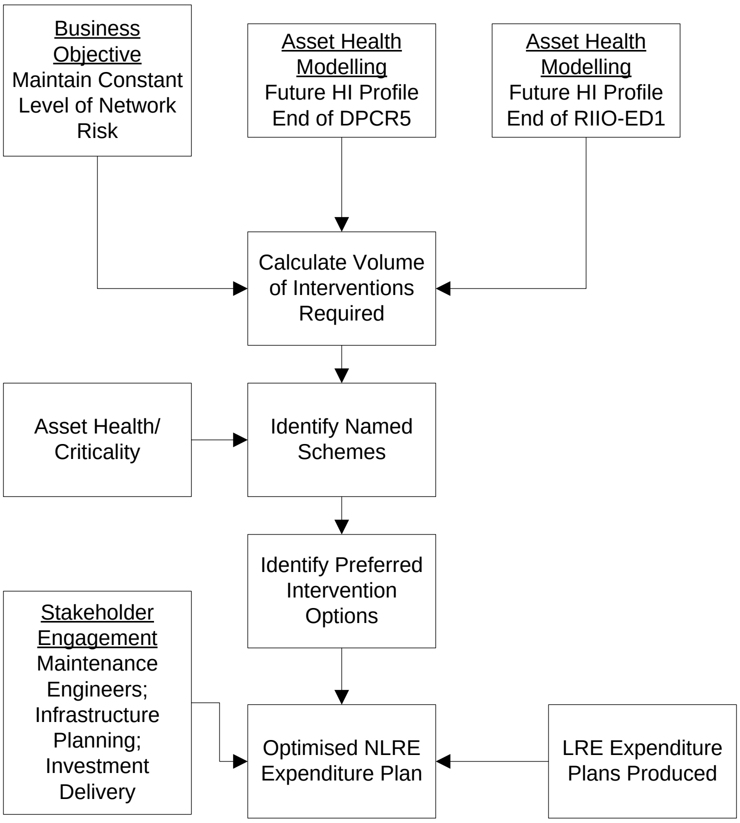



*Figure 15 – Constructing the ED1 NLRE plan*

## 7.2 Constructing the Plan

### 7.2.1 Intervention volumes

The business objective throughout the planning process for ED1 NLRE was to prevent any increase in the number of HI4/HI5 assets. To achieve this, the ARP model was used to determine the HI profiles for 132kV and EHV Transformers at the end of DPCR5 and at the end of ED1 to project how the number of HI4s and HI5s would increase without investment. This provided the basis for the volume of interventions required during ED1, with priority given to the assets with the highest HI/Criticality. Figure 16 and Figure 17 show how the numbers of HI4 and HI5 transformers are projected to change over the remainder of DPCR5 and ED1 both with and without the proposed investment. The HI profiles indicated are derived from condition related investment only and exclude the contribution from load related expenditure.

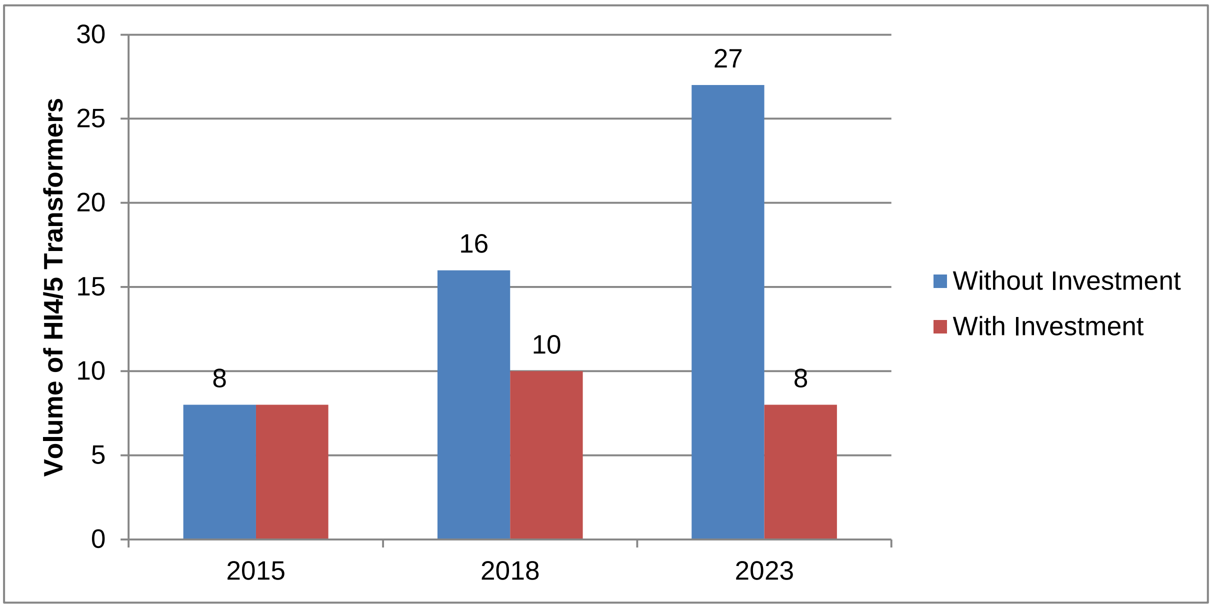



*Figure 16 – 132kV Transformer projected HI4 and HI5 volumes*

Source: ARP Model LW_TX_Jul2012

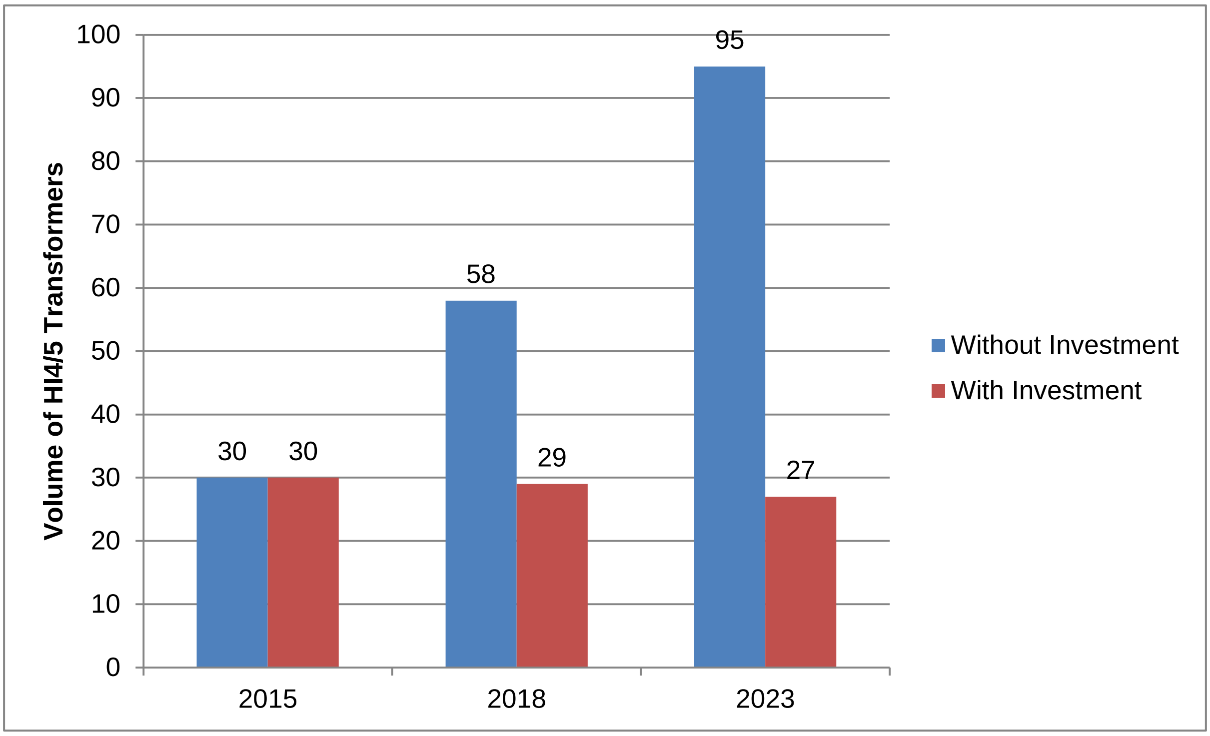



*Figure 17 – EHV Transformer projected HI4 and HI5 volumes*

Source: ARP Model LW_TX_Jul2012

#### 7.2.2 Intervention types

The five contributory HIs calculated by the ARP model (DGA, FFA, Oil Condition, Tap Changer and Condition Weighted Transformer) were used to determine the main driver for a transformer being HI4 or HI5. Those transformers with a DGA or FFA driver, indicating internal degradation, were selected for replacement, with the remaining transformers considered for refurbishment based on whole life cost analysis; an example is given in Appendix 4.

#### 7.2.3 Optimising the plan

Stakeholder engagement was an important part of the process to finalise the ED1 plan. Maintenance engineers were consulted, because they are the most familiar with the assets. They provided additional reassurance that the data used in the ARP model reflected their own assessment of each asset's condition. There was also detailed consultation with those involved in constructing the ED1 LRE expenditure plans to ensure the optimal investment for maximum achievement.

Consideration was also given to NLRE plans for other equipment classes to allow significant cost savings to be made by consolidating projects. An example is the condition-driven work at Sittingbourne Grid 132kV. Work is scheduled to start with replacement of the 33kV CBs in 2017, followed by GT3 and the 132kV FFC associated with GT3 in 2018/19.

## 7.3 Additional Considerations

Consideration was also given to the efficiency of the programme. In some cases, where multiple transformer interventions were planned on one site but an additional identical transformer on the site was projected to be an HI4 early in ED2, it was also included in the ED1 plan. It was deemed more efficient to adopt this approach due to the high project costs associated with a major intervention on transformers.

## 7.4 Asset Volumes and Expenditure

#### 7.4.1 Intervention volumes

Figure 18 and Figure 19 show the DPCR4/5 investment volumes followed by the required investment volumes for ED1 and ED2. Investment volumes can be found in more detail in Appendix 7.

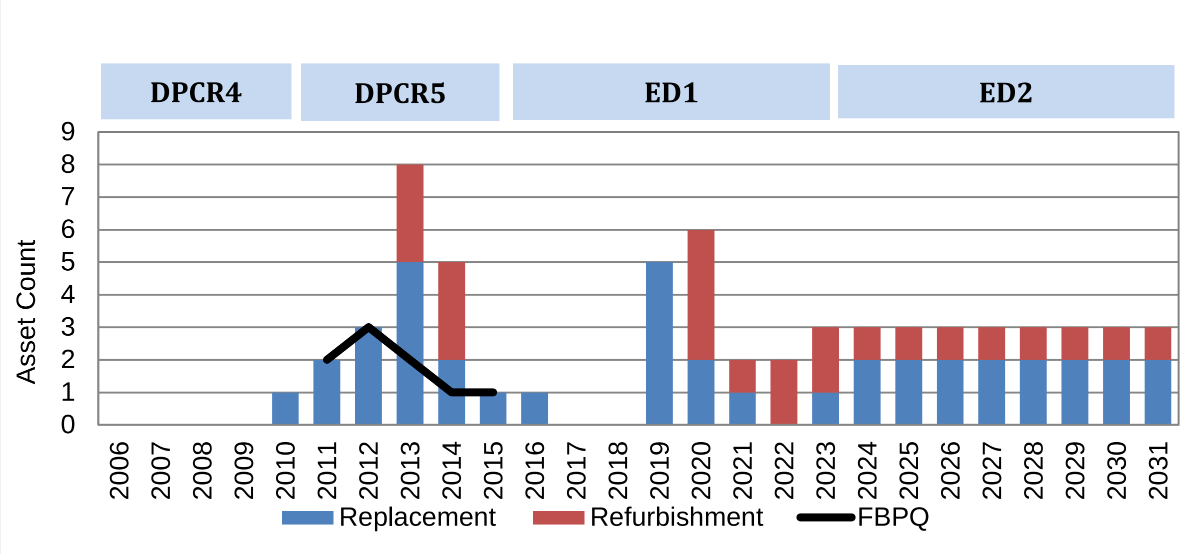



*Figure 18 – SPN 132kV Transformer intervention volumes DPCR5, ED1*

Sources: DPCR4 volumes: Table NL3 (DPCR5 FBPQ)
DPCR5 volumes: First three years – 2013 RIGs
DPCR5 volumes: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ volumes: EPN FBPQ Mapping NAMP 6.8
ED1 volumes: March 2014 ED1 Submission Data Tables
ED2 volumes: Analysis from Age Based Model

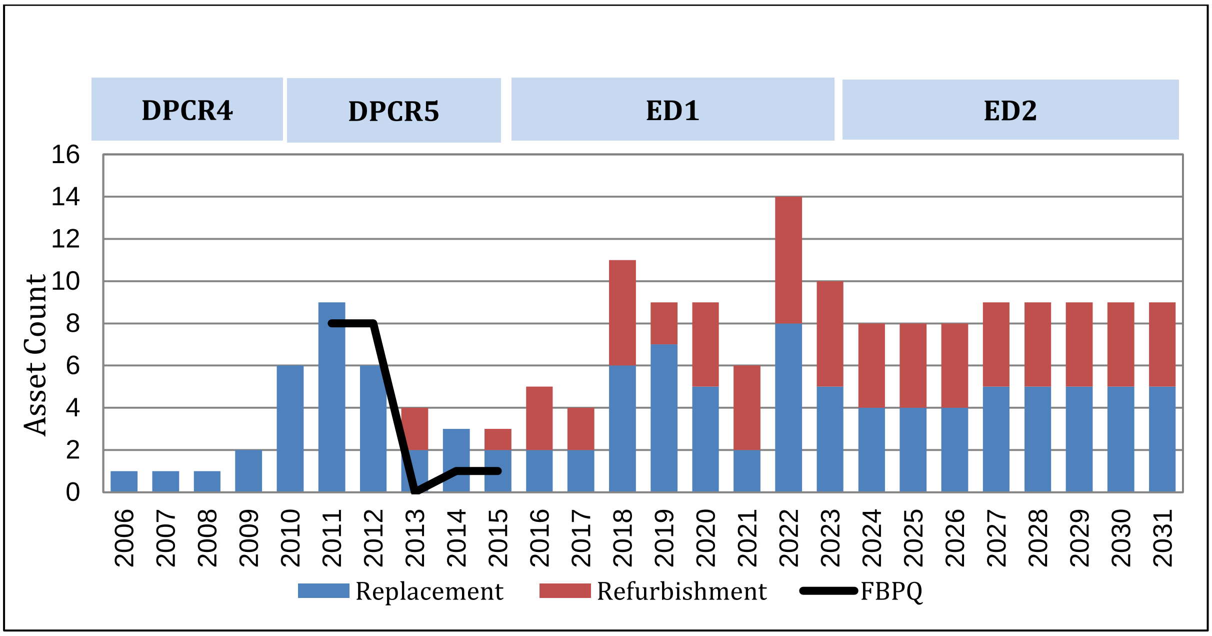



*Figure 19 – SPN EHV Transformer intervention volumes DPCR5, ED1*

Sources: DPCR4 volumes: Table NL3 (DPCR5 FBPQ)
DPCR5 volumes: First three years – 2013 RIGs
DPCR5 volumes: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ volumes: EPN FBPQ Mapping NAMP 6.8
ED1 volumes: March 2014 ED1 Submission Data Tables
ED2 volumes: Analysis from Age Based Model

### 7.4.2 Intervention expenditure

Proposed asset replacement expenditure for ED1 is shown in Figure 20 and Figure 21, along with those of DPCR4 and DPCR5 for comparison.

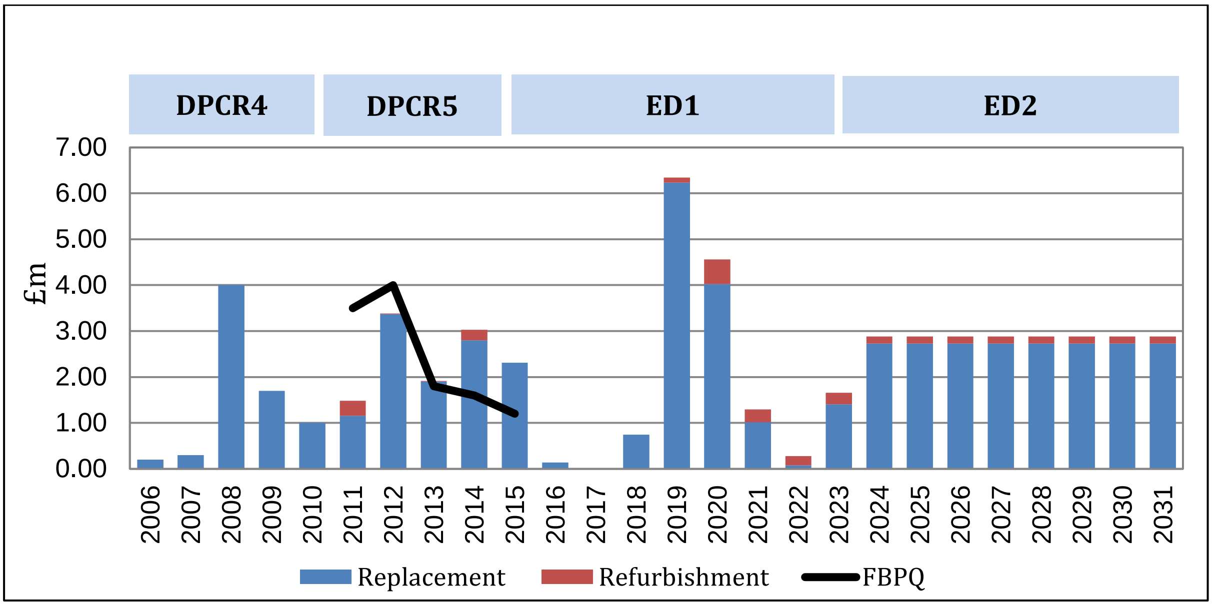



*Figure 20 – 132kV Transformer expenditure*

Sources: DPCR4 costs: Table NL1 (DPCR5 FBPQ)
DPCR5 costs: First three years – 2013 RIGs
DPCR5 costs: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ costs: EPN FBPQ Mapping NAMP 6.8
ED1 costs: 19th February 2014 NAMP
ED2 costs: Average from ED1 costs

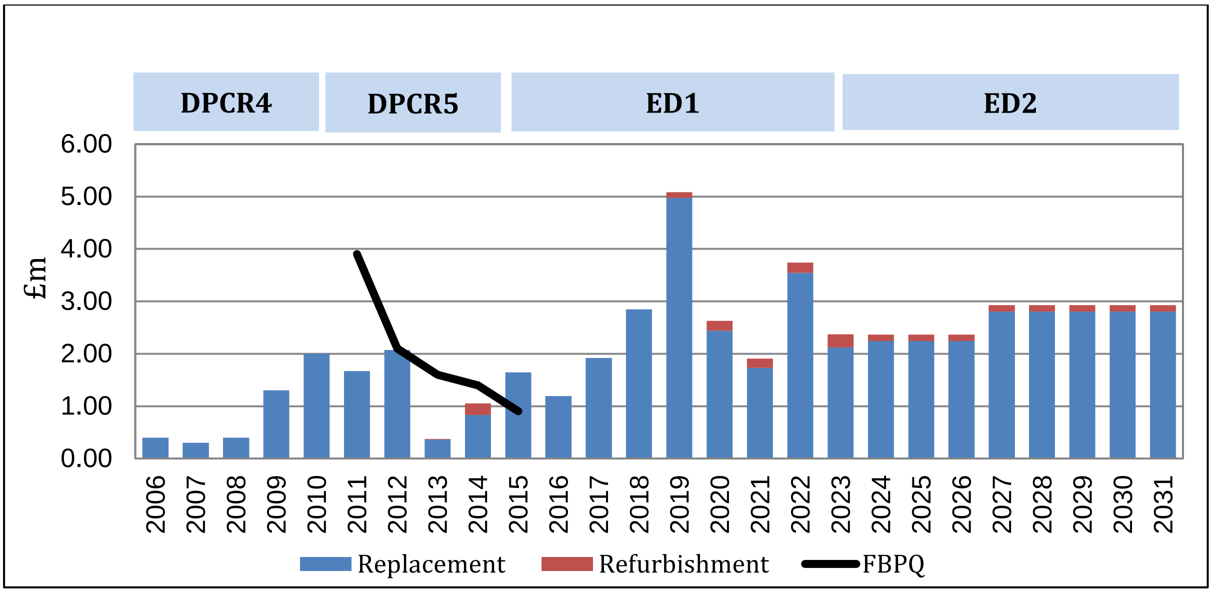



*Figure 21 – EHV Transformer expenditure*

Sources: DPCR4 costs: Table NL1 (DPCR5 FBPQ)
DPCR5 costs: First three years – 2013 RIGs
DPCR5 costs: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ costs: EPN FBPQ Mapping NAMP 6.8
ED1 costs: 19th February 2014 NAMP

ED2 costs: Average from ED1 costs

**Note:** Due to efficiency savings, careful risk management and the introduction of the refurbishment programme in the latter part of DPCR5, the volumes of interventions in the FBPQ were exceeded, while the costs were below the FPBQ level.

## 7.5 Commentary

### 7.5.1 132kV Transformers

Although the rate of 132kV transformer interventions in ED1 is only slightly less than DPCR5, the rate of NLRE replacement proposed for ED1 has reduced from 2.6 per year to 1.25 per year. The rate of replacement has been limited by the creation of the refurbishment programme. This improves asset health and risk while minimising short-term expenditure by extending the life of assets that would, in the past, have been considered for replacement. The improved data and better interpretation of the data allow the risks to be managed effectively.

The proposed plan will ensure that maximum asset life is achieved while optimising cost efficiency by co-ordinating projects on a given site and co-ordinating resources shared with LRE projects, although the phasing of planned achievement is not constant across ED1 as a result. An example of a project optimized in this way is at Sittingbourne Grid, discussed in section 7.2.3.

As seen in section 3.4, with no interventions the average age of the transformer population would increase significantly during the course of ED1. Extending this analysis to include planned interventions in ED1, Table 15 shows that the investment plan mitigates some of the increasing risk from the age profile of the assets. Our modern approach to asset data, heath and criticality will allow us to manage this risk effectively.

| | | | | Without investment | | With investment | |
|---|---|---|---|---|---|---|---|
| | Transformer population | Transformers over average asset life in 2015 | % Transformers over average asset life in 2015 | Transformers over average asset life in 2023 | % Transformers over average asset life in 2023 | Transformers over average asset life in 2023 | % Transformers over average asset life in 2023 |
| 132kV Transformers | 164 | 49 | 30% | 94 | 57% | 81 | 49% |

*Table 15 – Asset age vs. average asset life with ED1 investment (132kV Transformers)*

Sources: 2012 RIGs V5
ARP Model LW_TX_25Jul2012

Further work will be required and further development of health, criticality and risk modelling techniques to further refine the ED2 projections during ED1.

### 7.5.2 EHV Transformers

The rate of EHV Transformer interventions proposed for ED1 has increased from the DPCR5 programme from 5 per year to 8.5 per year. This increase in the rate of replacement has been limited by the creation of the refurbishment programme to just 4.6 per year. This improves asset health and risk while minimising short-term expenditure by extending the life of assets that would, in the past, have been considered for replacement. The improved data and better interpretation of the data allow the risks to be managed effectively.

This programme provides for a significant increase in the number of asset-health-driven interventions in ED1, while increasing expenditure by only £2m per year.

The proposed plan will ensure that maximum asset life is achieved while optimising cost efficiency by co-ordinating projects on a given site and co-ordinating resources shared with LRE projects, although the phasing of planned achievement is not constant across ED1 as a result.

As seen in section 3.4, with no interventions the average age of the EHV Transformer population would increase significantly during the course of ED1. Extending this analysis to include planned interventions in ED1, Table 16 shows that the investment plan mitigates some of the increasing risk from the age profile of the assets. Our modern approach to asset data, heath and criticality will allow us to manage this risk effectively.

| | | | | Without investment | | With NLRE investment | |
|---|---|---|---|---|---|---|---|
| | Transformer population | Transformers over average asset life in 2015 | % Transformers over average asset life in 2015 | Transformers over average asset life in 2023 | % Transformers over average asset life in 2023 | Transformers over average asset life in 2023 | % Transformers over average asset life in 2023 |
| EHV Transformers | 473 | 146 | 31% | 309 | 66% | 274 | 58% |

*Table 16 – Asset age vs. average asset life with ED1 investment (EHV Transformers)*

Sources: 2012 RIGs V5
ARP Model LW_TX_25Jul2012

Further work will be required and further development of health, criticality and risk modelling techniques to further refine the ED2 projections during ED1.

## 7.6 Sensitivity Analysis and Plan Validation

### 7.6.1 Average Asset Life sensitivity

As discussed in section 4.1.1, the Average Asset Life of each transformer is used in the ARP model to calculate the initial HI and also affects the degradation of the asset health over time. An analysis of the sensitivity of the ARP model due to variation in the Average Asset Life was carried out. Setting the correct Average Asset Life is an important part of using the ARP model, but is particularly difficult for transformer designs that are not yet approaching the end of their serviceable lives.

In Table 17 and Table 18, each Average Asset Life change of years +/- 1, 2 and 4 are represented as a percentage of the current population. With each change in Average Asset Life, there is a subsequent movement in the percentage of population in each Health Index. An Average Asset Life at 0 represents the current population split within each Health Index with intervention strategies applied. The two tables range from the start of ED1 (2015) and the end of ED1 (2023). These tables show the percentage population movements over the eight-year period and the impact any change in Average Asset Life will have on the asset group's HI profile.

| Average Asset Life change | **2015** percentage HI profile | | | | |
|---|---|---|---|---|---|
| | HI1 | HI2 | HI3 | HI4 | HI5 |
| -4 | 18.2 | 57.0 | 19.6 | 3.2 | 1.9 |
| -2 | 18.2 | 55.8 | 20.8 | 3.2 | 1.9 |
| -1 | 18.2 | 55.2 | 21.4 | 3.2 | 1.9 |
| 0 | 18.8 | 54.5 | 21.4 | 3.2 | 1.9 |
| 1 | 18.8 | 53.9 | 22.0 | 3.2 | 1.9 |
| 2 | 18.8 | 53.9 | 22.0 | 3.2 | 1.9 |
| 4 | 18.8 | 53.9 | 22.0 | 3.2 | 1.9 |

| Average Asset Life change | **2023** percentage HI profile | | | | |
|---|---|---|---|---|---|
| | HI1 | HI2 | HI3 | HI4 | HI5 |
| -4 | 13.0 | 40.3 | 39.6 | 5.1 | 1.9 |
| -2 | 13.0 | 40.9 | 40.3 | 3.9 | 1.9 |
| -1 | 13.0 | 40.9 | 40.3 | 3.9 | 1.9 |
| 0 | 13.0 | 40.9 | 40.3 | 3.9 | 1.9 |
| 1 | 13.6 | 40.3 | 40.3 | 3.9 | 1.9 |
| 2 | 13.6 | 40.3 | 40.3 | 3.9 | 1.9 |
| 4 | 13.6 | 40.9 | 39.6 | 4.5 | 1.3 |

*Table 17 – 132kV Transformer sensitivity analysis results*

Source: DecisionLab Ltd Analysis February 2013

| Average Asset Life change | **2015** percentage HI profile | | | | |
|---|---|---|---|---|---|
| | HI1 | HI2 | HI3 | HI4 | HI5 |
| -4 | 11.0 | 63.1 | 20.2 | 3.1 | 2.5 |
| -2 | 11.0 | 64.0 | 19.4 | 3.3 | 2.3 |
| -1 | 11.0 | 64.4 | 19.0 | 3.3 | 2.3 |
| 0 | 11.0 | 64.8 | 18.5 | 3.3 | 2.3 |
| 1 | 11.0 | 65.2 | 18.1 | 3.3 | 2.3 |
| 2 | 11.0 | 65.0 | 18.3 | 3.3 | 2.3 |
| 4 | 11.0 | 65.0 | 18.3 | 3.3 | 2.3 |

| Average Asset Life change | **2023** percentage HI profile | | | | |
|---|---|---|---|---|---|
| | HI1 | HI2 | HI3 | HI4 | HI5 |
| -4 | 11.3 | 36.0 | 45.4 | 4.8 | 2.5 |
| -2 | 11.3 | 36.9 | 44.8 | 5.0 | 2.1 |
| -1 | 11.3 | 38.5 | 43.5 | 4.6 | 2.1 |
| 0 | 11.3 | 39.2 | 43.3 | 4.2 | 2.1 |
| 1 | 11.3 | 39.4 | 43.3 | 4.0 | 2.1 |
| 2 | 11.3 | 39.6 | 43.3 | 3.7 | 2.1 |
| 4 | 11.3 | 39.8 | 43.5 | 3.5 | 1.9 |

*Table 18 – EHV Transformer sensitivity analysis results*

Source: DecisionLab Ltd Analysis February 2013

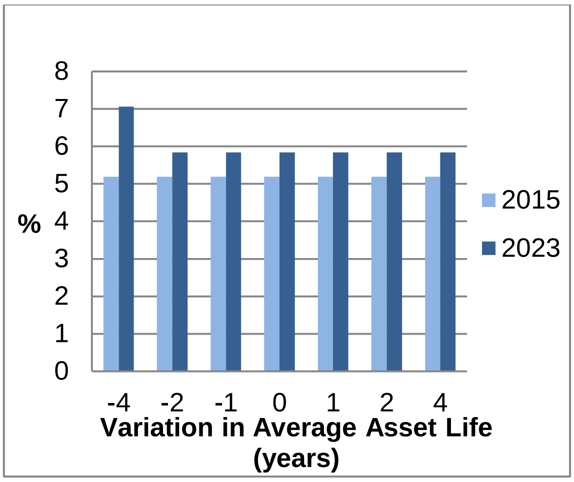



*Figure 22 – % variation in HI4 and HI5 132kV Transformers*

Source: DecisionLab Ltd Analysis February 2013

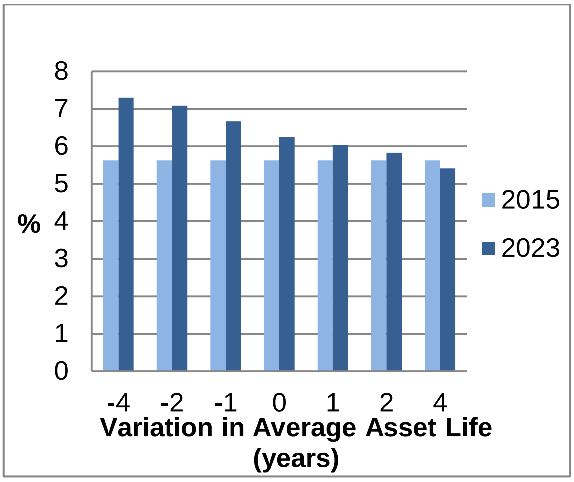



*Figure 23 – % variation in HI4 and HI5 EHV Transformers*

Source: DecisionLab Ltd Analysis February 2013

Figure 22 and Figure 23 represent summed HI4s and HI5s as a percentage of the population, showing the change at each Average Asset Life iteration, comparing 2015 and 2023.

The analysis shows that changing the Average Asset Life of 132kV Transformers by up ± four years has limited effect on the proportion of HI4/HI5 assets in 2015. Reducing the Average Asset Life by four years increases the HI4/HI5 assets in 2023 from 5.8% to 7.0%. For EHV Transformers, the variation in 2015 is also limited. In 2023 the proportion of HI4/HI5 ranges from 5.4% to 7.3%. This shows that the ED1 investment plan is robust to variations in Average Asset Life. The consultant's full report can be found in Appendix 6.

### 7.6.2 Network risk

As mentioned in section 4, the ARP model is able to produce a criticality index (C1 to C4) for each individual asset, although this is a new concept and is still being developed. The criticality index can be used with the Health Index to give an indication of the level of risk that can be seen on the network. Table 19 and Table 20 show the HI and criticality matrix for 2015 and 2023 with investment during ED1.

| | Criticality | Units | Estimated asset health and criticality profile 2015 | | | | | Asset register |
|---|---|---|---|---|---|---|---|---|
| | | | Asset Health Index | | | | | 2015 |
| | | | HI1 | HI2 | HI3 | HI4 | HI5 | |
| EHV Transformer | Low | No. TX | 21 | 140 | 22 | 8 | 3 | 194 |
| | Average | No. TX | 29 | 154 | 59 | 11 | 6 | 259 |
| | High | No. TX | 4 | 29 | 7 | 0 | 2 | 42 |
| | Very high | No. TX | 0 | 0 | 0 | 0 | 0 | 0 |
| 132kV Transformer | Low | No. TX | 6 | 26 | 5 | 3 | 1 | 41 |
| | Average | No. TX | 19 | 79 | 24 | 1 | 2 | 125 |
| | High | No. TX | 3 | 9 | 4 | 1 | 0 | 17 |
| | Very high | No. TX | 0 | 0 | 0 | 0 | 0 | 0 |

*Table **19** – Projected 2015 HI-CI matrix*

Sources: ARP Model LW_TX_25Jul2012
ARP Model LW_TX_27Nov2012

| | Criticality | Units | Estimated asset health and criticality profile 2023 | | | | | Asset register |
|---|---|---|---|---|---|---|---|---|
| | | | Asset Health Index | | | | | 2023 |
| | | | HI1 | HI2 | HI3 | HI4 | HI5 | |
| EHV Transformer | Low | No. TX | 17 | 92 | 78 | 1 | 6 | 194 |
| | Average | No. TX | 35 | 109 | 96 | 15 | 4 | 259 |
| | High | No. TX | 4 | 14 | 23 | 0 | 1 | 42 |
| | Very high | No. TX | 0 | 0 | 0 | 0 | 0 | 0 |
| 132kV Transformer | Low | No. TX | 6 | 18 | 15 | 0 | 1 | 40 |
| | Average | No. TX | 12 | 74 | 34 | 3 | 2 | 125 |
| | High | No. TX | 1 | 8 | 6 | 2 | 0 | 17 |
| | Very high | No. TX | 0 | 0 | 0 | 0 | 0 | 0 |

*Table 20 – Projected 2023 HI-CI matrix with investment*

Sources: ARP Model LW_TX_25Jul2012

ARP Model LW_TX_27Nov2012

# 8.0 Deliverability

The SPN Capital Programme Investment Delivery Team, key stakeholders in the development of the plan, will carry out all infrastructure asset intervention projects, both LRE and NLRE. They have confirmed that the proposed transformer intervention plan is achievable in co-ordination with other planned investments. The programme of transformer interventions will be coordinated with that of other asset groups to ensure efficient delivery.

# Appendices

## Appendix 1 – Age Profiles

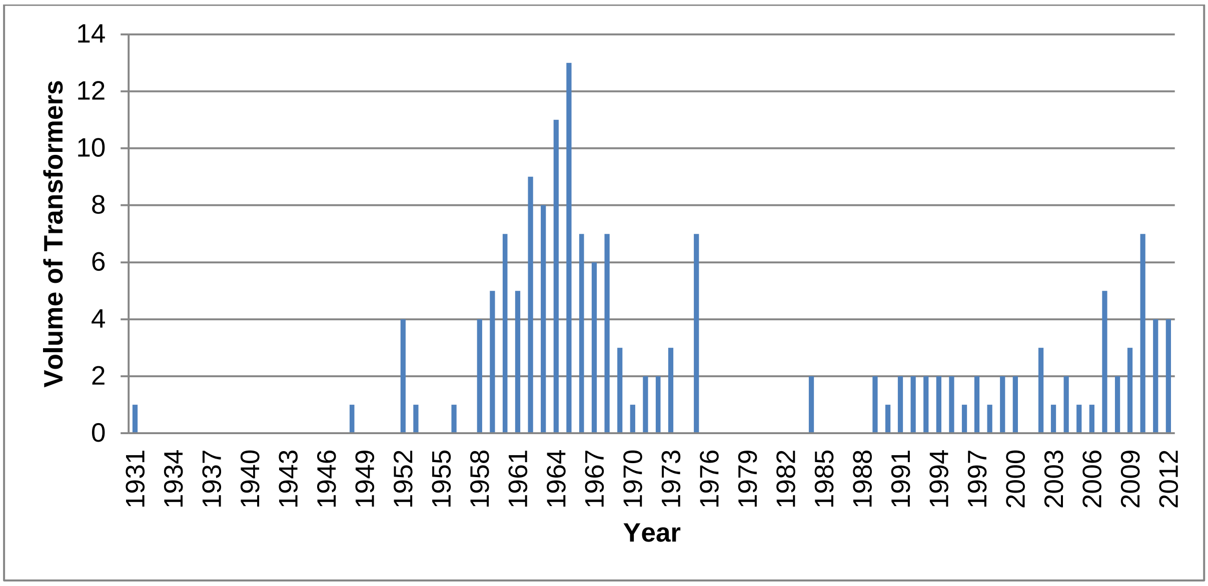



*Figure 24: SPN 132kV Transformer age profile*

Source: 2012 RIGs V5

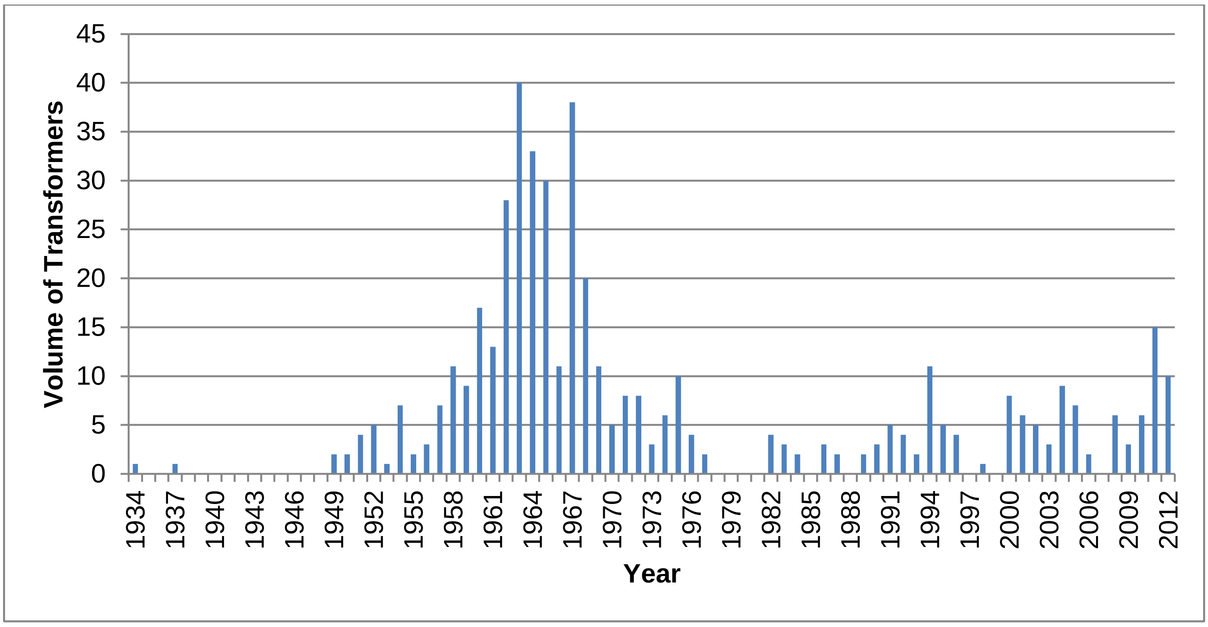



*Figure 25: SPN EHV Transformer age profile*

Source: 2012 RIGs V5

# Appendix 2 – HI and Criticality Profiles

| | Criticality | Units | Estimated asset health and criticality profile 2015 | | | | | Asset register |
|---|---|---|---|---|---|---|---|---|
| | | | Asset Health Index | | | | | 2015 |
| | | | HI1 | HI2 | HI3 | HI4 | HI5 | |
| EHV Transformer | Low | No. TX | 21 | 140 | 22 | 8 | 3 | 194 |
| | Average | No. TX | 29 | 154 | 59 | 11 | 6 | 259 |
| | High | No. TX | 4 | 29 | 7 | 0 | 2 | 42 |
| | Very high | No. TX | 0 | 0 | 0 | 0 | 0 | 0 |
| 132kV Transformer | Low | No. TX | 6 | 26 | 5 | 3 | 1 | 41 |
| | Average | No. TX | 19 | 79 | 24 | 1 | 2 | 125 |
| | High | No. TX | 3 | 9 | 4 | 1 | 0 | 17 |
| | Very high | No. TX | 0 | 0 | 0 | 0 | 0 | 0 |

*Table 21 – Projected 2015 HI-CI matrix*

Sources: ARP Model LW_TX_25Jul2012
ARP Model LW_TX_27Nov2012

| | Criticality | Units | Estimated asset health and criticality profile 2023 | | | | | Asset register |
|---|---|---|---|---|---|---|---|---|
| | | | Asset Health Index | | | | | 2023 |
| | | | HI1 | HI2 | HI3 | HI4 | HI5 | |
| EHV Transformer | Low | No. TX | 17 | 92 | 78 | 1 | 6 | 194 |
| | Average | No. TX | 35 | 109 | 96 | 15 | 4 | 259 |
| | High | No. TX | 4 | 14 | 23 | 0 | 1 | 42 |
| | Very high | No. TX | 0 | 0 | 0 | 0 | 0 | 0 |
| 132kV Transformer | Low | No. TX | 6 | 18 | 15 | 0 | 1 | 40 |
| | Average | No. TX | 12 | 74 | 34 | 3 | 2 | 125 |
| | High | No. TX | 1 | 8 | 6 | 2 | 0 | 17 |
| | Very high | No. TX | 0 | 0 | 0 | 0 | 0 | 0 |

*Table 22 – Projected 2023 HI-CI matrix with investment*

Sources: ARP Model LW_TX_25Jul2012
ARP Model LW_TX_27Nov2012

| | | HI1 | HI2 | HI3 | HI4 | HI5 |
|---|---|---|---|---|---|---|
| 132kV Transformers | Start of ED1 | 28 | 114 | 33 | 5 | 3 |
| | End of ED1 without investment | 10 | 91 | 55 | 22 | 5 |
| | End of ED1 with investment | 19 | 100 | 55 | 5 | 3 |
| EHV Transformers | Start of ED1 | 54 | 323 | 88 | 19 | 11 |
| | End of ED1 without investment | 19 | 184 | 197 | 67 | 28 |
| | End of ED1 with investment | 56 | 215 | 197 | 16 | 11 |

*Table 23: Project HI deterioration summary (Source - ARP Model LW_TX_25Jul2012)*

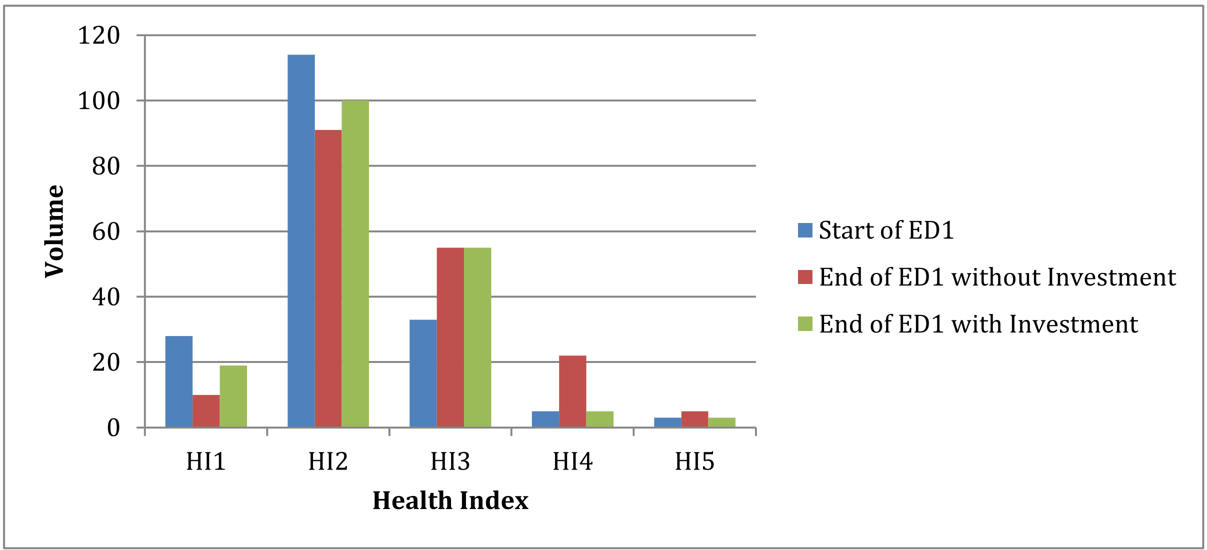



*Figure 26: 132kV Transformer HI Profiles*

Source: ARP Model LW_TX_Jul2012

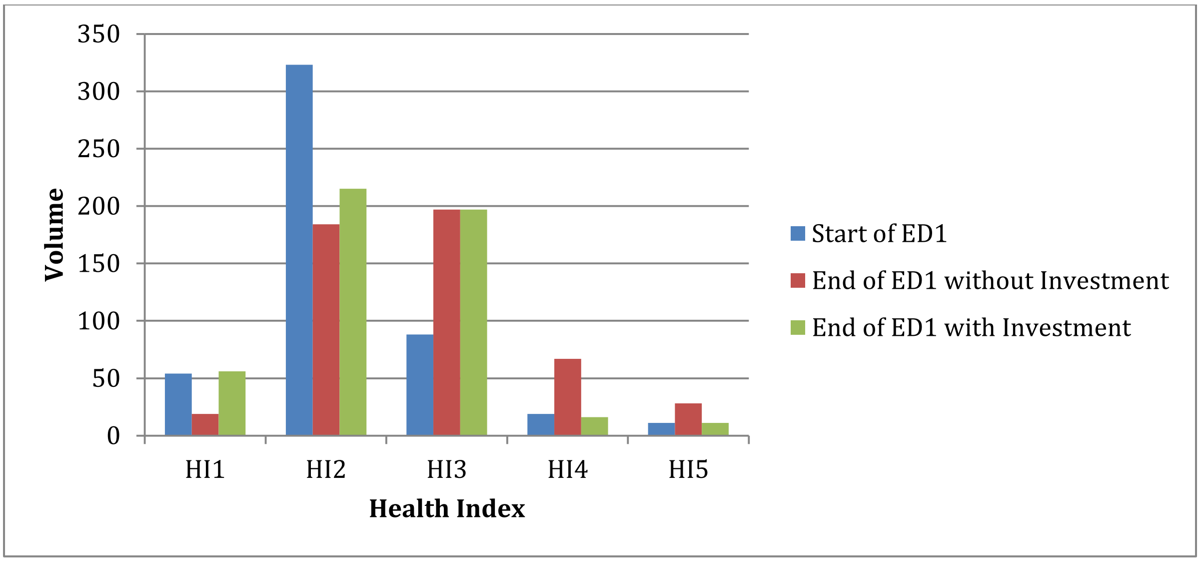



*Figure 27: EHV Transformer HI Profiles*

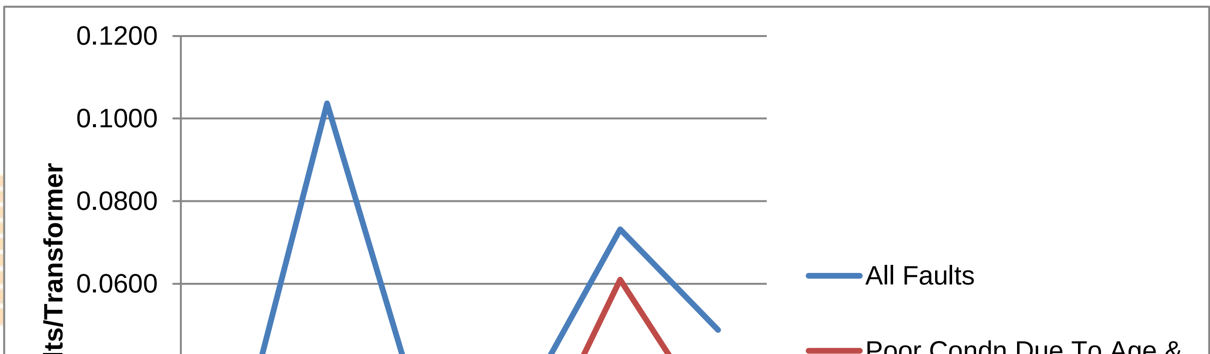
Source: ARP Model LW_TX_Jul2012

## Appendix 3 – Fault Data

| SPN 132kV Transformers | | | | | | |
|---|---|---|---|---|---|---|
| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** |
| All faults | 2 | 17 | 4 | 5 | 12 | 8 |
| Deterioration due to ageing or wear (excluding corrosion) | 2 | 4 | | 2 | 10 | 4 |
| Deterioration due to ageing or wear (including corrosion) | 2 | 4 | | 2 | 10 | 4 |
| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** |
| All faults | 0.0122 | 0.1037 | 0.0244 | 0.0305 | 0.0732 | 0.0488 |
| Poor condition due to age and wear | 0.0122 | 0.0244 | 0.0000 | 0.0122 | 0.0610 | 0.0244 |

*Table 24: 132kV Transformer historic fault data*

Source: UK Power Networks Fault Analysis Cube



Source: UK Power Networks Fault Analysis Cube

| SPN EHV Transformers | | | | | | |
|---|---|---|---|---|---|---|
| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** |
| All faults | 11 | 18 | 8 | 15 | 16 | 15 |
| Deterioration due to ageing or wear (excluding corrosion) | 4 | 2 | 2 | 5 | 5 | 5 |
| Deterioration due to ageing or wear (including corrosion) | 4 | 2 | 2 | 5 | 5 | 5 |
| | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** |
| All Faults | 0.0233 | 0.0381 | 0.0169 | 0.0317 | 0.0338 | 0.0317 |
| Poor condition due to age and wear | 0.0085 | 0.0042 | 0.0042 | 0.0106 | 0.0106 | 0.0106 |

*Table 25: EHV Transformer historic fault data*

Source: UK Power Networks Fault Analysis Cube

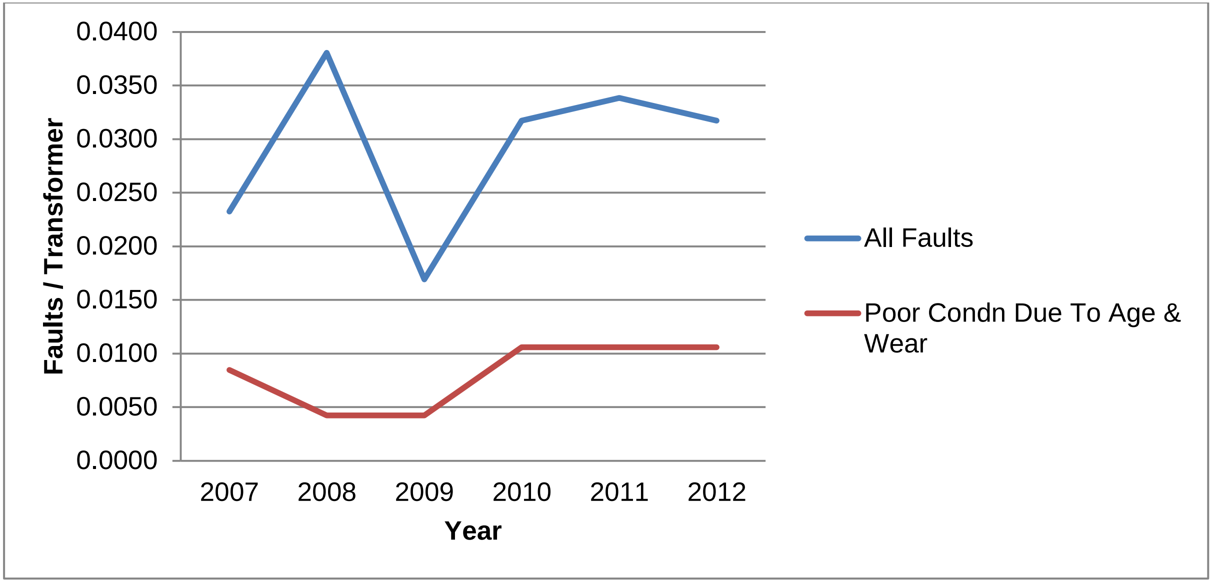



*Figure 29: EHV Transformer historic fault rates (Source: UK Power Networks Fault Analysis Cube)*

Source: UK Power Networks Fault Analysis Cube

## Appendix 4 – WLC Case Study

All of the cost numbers displayed in this document are before the application of on-going efficiencies and real price effects.

| Whole life cost description | 132 kV Transformer: replacement v refurbishment analysis. |
|---|---|
| Starting assumption (same for all scenarios) | It is assumed the transformer is 40 years old at the beginning of the scenario, that it has a current new purchase cost of £450k and has an average useful operating life of 60 years. |

| Scenario 1 | |
|---|---|
| Assumptions specific to this scenario | 40 year old Tx with slow speed tap changer requiring main tank and selector DGA annually, diverter maintenance every 4 years and selector maintenance every 16 years. Inspection carried out evry 6 months. Replaced after 10 years with a new transformer with modern tap changer requiring maintenance every 8 years. |

| Description of costs/(income) items | Year 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Notional purchase cost of a 50 year old transformer (i.e.: 19 years remaining service life) | 330 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 330 |
| Annual inspection & maintenance costs of initial transformer | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | 16 |
| Purchase of replacement transformer in year 10 | | | | | | | | | | 1,200 | | | | | | | | | | | | | | | | | | | | | 1,200 |
| Annual inspection & maintenance costs of replacement transformer | | | | | | | | | | 1 | 1 | 1 | 1 | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 | 39 |
| Residual value of replacement transformer at end of scenario (i.e.: 49 years remaining life) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | -852 | -852 |
| Net cash flow | 331 | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 1202 | 1 | 1 | 1 | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 7 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | -845 | 733 |

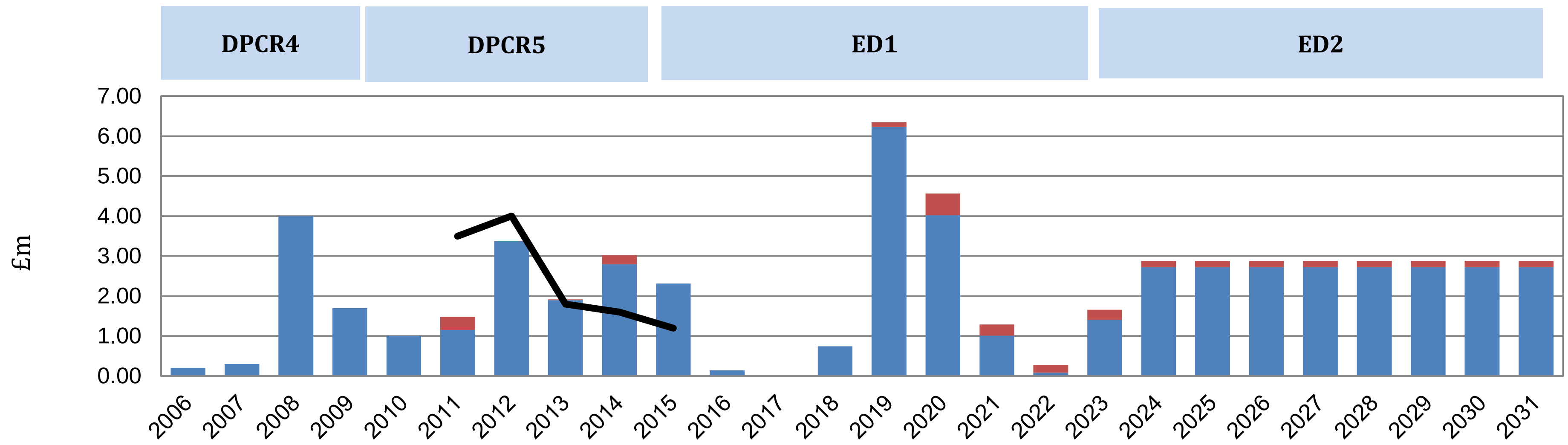
| Discount rate: Select 6.85% | 6.85% |
|---|---|
| Discounted whole life cost | 833 |

| Scenario 2 | |
|---|---|
| Assumptions specific to this scenario | 40 year old Tx with slow speed tap changer requiring main tank and selector DGA annually, diverter maintenance every 4 years and selector maintenance every 16 years. Inspection carried out evry 6 months. Refurbished after 10 years, providing 15 years further servicable life after which it is replaced with a new transformer with modern tap changer requiring mainteance every 8 years. |

| Description of costs/(income) items | Year 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 | Totals |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Notional purchase cost of a 50 year old transformer (i.e.: 19 years remaining service life) | 330 | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | 330 |
| Annual inspection costs of initial transformer | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 1 | | | | | | | | | | | | | | | | | | | | | 16 |
| Transformer Refurbishment in Year 10 | | | | | | | | | | 110 | | | | | | | | | | | | | | | | | | | | | 110 |
| Annual inspection costs of refurbished transformer | | | | | | | | | | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 7 | 1 | | | | | | 31 |
| Purchase of replacement transformer in year 25 | | | | | | | | | | | | | | | | | | | | | | | | | 1,200 | | | | | | 1,200 |
| Annual inspection costs of replacementtransformer | | | | | | | | | | | | | | | | | | | | | | | | | 1 | 1 | 1 | 1 | 7 | 1 | 12 |
| Residual value of replacement transformer at end of scenario (i.e.: 64 years remaining life) | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | -939 | -939 |
| Net cash flow | 331 | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 112 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 4 | 1 | 1 | 1 | 7 | 1202 | 1 | 1 | 1 | 7 | -938 | 760 |

| Discount rate: Select 6.85% | 6.85% |
|---|---|
| Discounted whole life cost | 489 |

# Appendix 5 NLRE Expenditure Plan

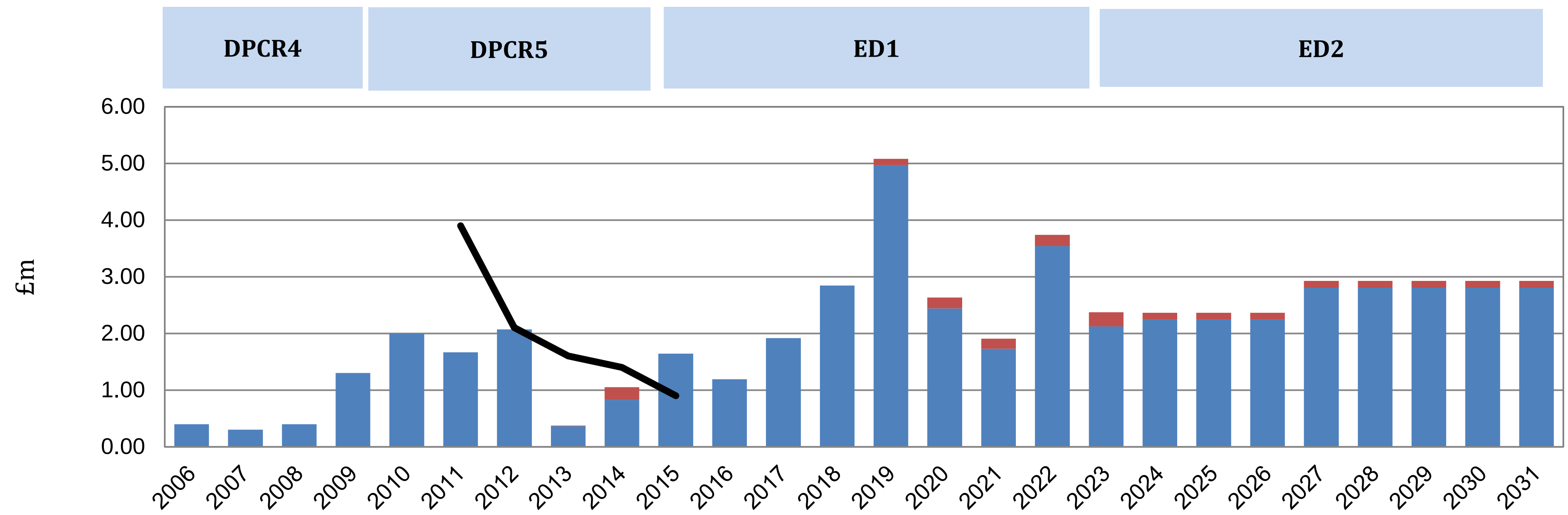



| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Refurbishment | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.33 | 0.01 | 0.01 | 0.23 | 0.00 | 0.00 | 0.00 | 0.00 | 0.11 | 0.54 | 0.28 | 0.20 | 0.25 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Replacement | 0.20 | 0.30 | 4.00 | 1.70 | 1.00 | 1.16 | 3.37 | 1.90 | 2.80 | 2.31 | 0.14 | 0.00 | 0.74 | 6.23 | 4.02 | 1.01 | 0.08 | 1.41 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 | 2.73 |
| FBPQ | | | | | | 3.50 | 4.00 | 1.80 | 1.60 | 1.20 | | | | | | | | | | | | | | | | |

Replacement  Refurbishment  FBPQ

*Figure 30: 132kV NLRE investment expenditure*

Sources: DPCR4 costs: Table NL1 (DPCR5 FBPQ)
DPCR5 costs: First three years – 2013 RIGs
DPCR5 costs: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ costs: EPN FBPQ Mapping NAMP 6.8
ED1 costs: 19th February 2014 NAMP
ED2 costs: Average from ED1 costs



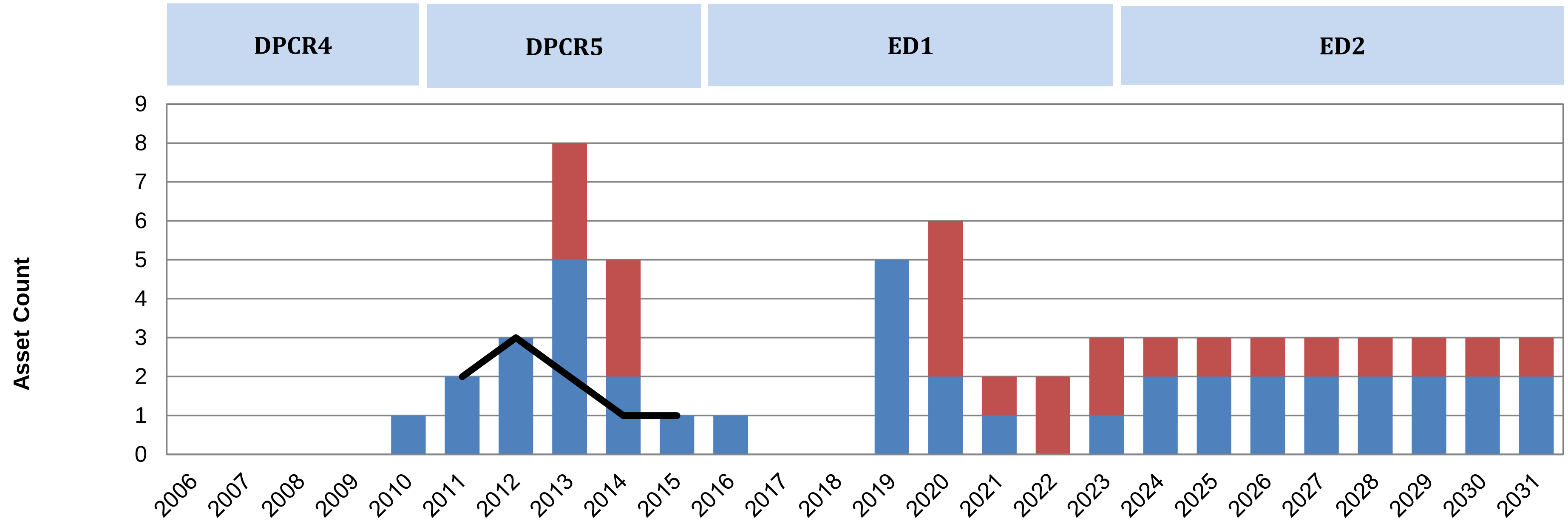

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Refurbishment | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0.01 | 0.22 | 0 | 0 | 0 | 0 | 0.11 | 0.19 | 0.18 | 0.2 | 0.25 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 | 0.12 |
| Replacement | 0.40 | 0.30 | 0.40 | 1.30 | 2.00 | 1.67 | 2.07 | 0.36 | 0.83 | 1.64 | 1.19 | 1.92 | 2.85 | 4.97 | 2.44 | 1.73 | 3.54 | 2.12 | 2.24 | 2.24 | 2.24 | 2.81 | 2.81 | 2.81 | 2.81 | 2.81 |
| FBPQ | | | | | | 3.90 | 2.10 | 1.60 | 1.40 | 0.90 | | | | | | | | | | | | | | | | |

Replacement   Refurbishment   FBPQ

*Figure 31: EHV NLRE investment expenditure*

Sources: DPCR4 costs: Table NL1 (DPCR5 FBPQ)
DPCR5 costs: First three years – 2013 RIGs
DPCR5 costs: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ costs: EPN FBPQ Mapping NAMP 6.8

ED1 costs: 19th February 2014 NAMP
ED2 costs: Average from ED1 costs



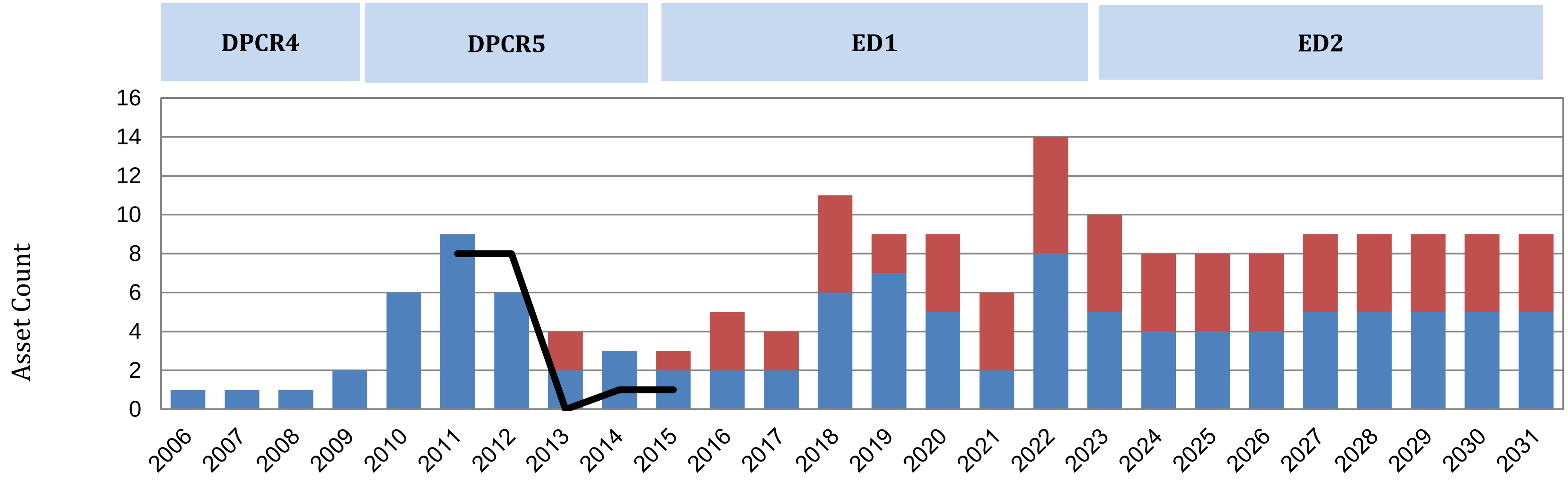

| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Refurbishment | | | | | | 0 | 0 | 3 | 3 | | 0 | 0 | 0 | 0 | 4 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Replacement | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 5 | 2 | 1 | 1 | 0 | 0 | 5 | 2 | 1 | 0 | 1 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| FBPQ | | | | | | 2 | 3 | 2 | 1 | 1 | | | | | | | | | | | | | | | | |

Replacement Refurbishment FBPQ

*Figure 32: 132kV NLRE investment volumes*

Sources: DPCR4 volumes: Table NL3 (DPCR5 FBPQ)
DPCR5 volumes: First three years – 2013 RIGs

DPCR5 volumes: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ volumes: EPN FBPQ Mapping NAMP 6.8
ED1 volumes: March 2014 ED1 Submission Data Tables
ED2 volumes: Analysis from Age Based Model




| | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030 | 2031 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Refurbishment | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2 | 0 | 1 | 3 | 2 | 5 | 2 | 4 | 4 | 6 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 4 |
| Replacement | 1 | 1 | 1 | 2 | 6 | 9 | 6 | 2 | 3 | 2 | 2 | 2 | 6 | 7 | 5 | 2 | 8 | 5 | 4 | 4 | 4 | 5 | 5 | 5 | 5 | 5 |
| FBPQ | | | | | | 8 | 8 | 0 | 1 | 1 | | | | | | | | | | | | | | | | |

Replacement   Refurbishment   FBPQ

*Figure 33: EHV NLRE investment volumes*

Sources: DPCR4 volumes: Table NL3 (DPCR5 FBPQ)
DPCR5 volumes: First three years – 2013 RIGs

DPCR5 volumes: Last two years – 14 June 2013 NAMP
DPCR5 FBPQ volumes: EPN FBPQ Mapping NAMP 6.8
ED1 volumes: March 2014 ED1 Submission Data Tables
ED2 volumes: Analysis from Age Based Model

# Appendix 6 Sensitivity Analysis

# Sensitivity Analysis:

## Asset Risk and Prioritisation Model for SPN Transformers

(written by Decision Lab)

**Introduction**

This is a report on the sensitivity analysis conducted on the Asset Risk and Prioritisation (ARP) Model, developed by EA Technology and used to support the asset replacement and investment strategy for SPN transformers, which is included in the ED1 plan.

The objective is to understand how the Health Index profile of assets may change if the Average Asset Life of assets does not turn out as predicted.

An input to the ARP model is the starting asset population in each Health Index, which is different in each region. Therefore, sensitivity analysis has been done on a region-by-region basis.

**The Asset Risk and Prioritisation Model**

The ARP model uses database information about each individual asset, and models many parameters to predict the Health Index of each asset in the future. Significant parameters are age, location, loading and current Average Asset Life.

**Sensitivity Analysis**

Variation in average asset life can occur, but this is significantly less than the variation in asset lives of individual transformers.

Standard Average Asset Lives are used in the ARP model. For transformers, these are specified for each manufacturer. The values are 55, 40 and 35 years. In 2012, about 72% of the SPN transformers have a current Average Asset Life of 55 years, and about 25% have an Average Asset Life of 40 years. This study covered the full population of 132kV and EHV Transformers.

Using 2012 asset data and the replacement plans up to 2023, the ARP model was used to predict the Health Index of each asset at the beginning and end of ED1. This was then repeated, varying each current Average Asset Life by +/- 1, 2 and 4 years.

All results are shown below as the percentages of either the 132kV transformer or EHV Transformer asset population.

**132kV TX**

| Average Asset Life change | **2015** percentage HI profile | | | | |
|---|---|---|---|---|---|
| | HI1 | HI2 | HI3 | HI4 | HI5 |
| -4 | 18.2 | 57.0 | 19.6 | 3.2 | 1.9 |
| -2 | 18.2 | 55.8 | 20.8 | 3.2 | 1.9 |
| -1 | 18.2 | 55.2 | 21.4 | 3.2 | 1.9 |
| 0 | 18.8 | 54.5 | 21.4 | 3.2 | 1.9 |
| 1 | 18.8 | 53.9 | 22.0 | 3.2 | 1.9 |
| 2 | 18.8 | 53.9 | 22.0 | 3.2 | 1.9 |
| 4 | 18.8 | 53.9 | 22.0 | 3.2 | 1.9 |

| Average Asset Life change | **2023** percentage HI profile | | | | |
|---|---|---|---|---|---|
| | HI1 | HI2 | HI3 | HI4 | HI5 |
| -4 | 13.0 | 40.3 | 39.6 | 5.1 | 1.9 |
| -2 | 13.0 | 40.9 | 40.3 | 3.9 | 1.9 |
| -1 | 13.0 | 40.9 | 40.3 | 3.9 | 1.9 |
| 0 | 13.0 | 40.9 | 40.3 | 3.9 | 1.9 |
| 1 | 13.6 | 40.3 | 40.3 | 3.9 | 1.9 |
| 2 | 13.6 | 40.3 | 40.3 | 3.9 | 1.9 |
| 4 | 13.6 | 40.9 | 39.6 | 4.5 | 1.3 |

**EHV TX**

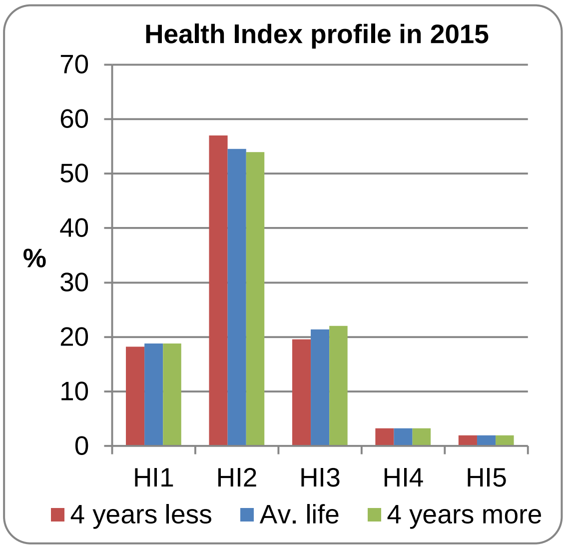
| Average Asset Life change | **2015** percentage HI profile | | | | |
|---|---|---|---|---|---|
| | HI1 | HI2 | HI3 | HI4 | HI5 |
| -4 | 11.0 | 63.1 | 20.2 | 3.1 | 2.5 |
| -2 | 11.0 | 64.0 | 19.4 | 3.3 | 2.3 |
| -1 | 11.0 | 64.4 | 19.0 | 3.3 | 2.3 |
| 0 | 11.0 | 64.8 | 18.5 | 3.3 | 2.3 |
| 1 | 11.0 | 65.2 | 18.1 | 3.3 | 2.3 |
| 2 | 11.0 | 65.0 | 18.3 | 3.3 | 2.3 |
| 4 | 11.0 | 65.0 | 18.3 | 3.3 | 2.3 |

| Average Asset Life change | **2023** percentage HI profile | | | | |
|---|---|---|---|---|---|
| | HI1 | HI2 | HI3 | HI4 | HI5 |
| -4 | 11.3 | 36.0 | 45.4 | 4.8 | 2.5 |
| -2 | 11.3 | 36.9 | 44.8 | 5.0 | 2.1 |
| -1 | 11.3 | 38.5 | 43.5 | 4.6 | 2.1 |
| 0 | 11.3 | 39.2 | 43.3 | 4.2 | 2.1 |
| 1 | 11.3 | 39.4 | 43.3 | 4.0 | 2.1 |
| 2 | 11.3 | 39.6 | 43.3 | 3.7 | 2.1 |
| 4 | 11.3 | 39.8 | 43.5 | 3.5 | 1.9 |

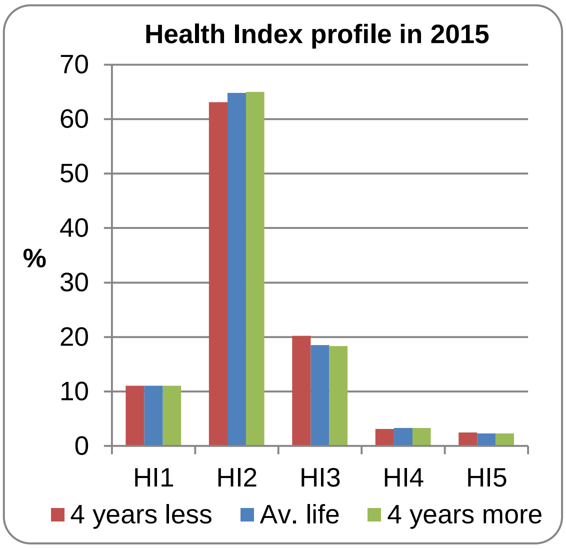
As the percentages above are rounded, the sum of a row may be 0.2% above or below 100%.

The upper and lower and current Average Asset Life cases are charted below.

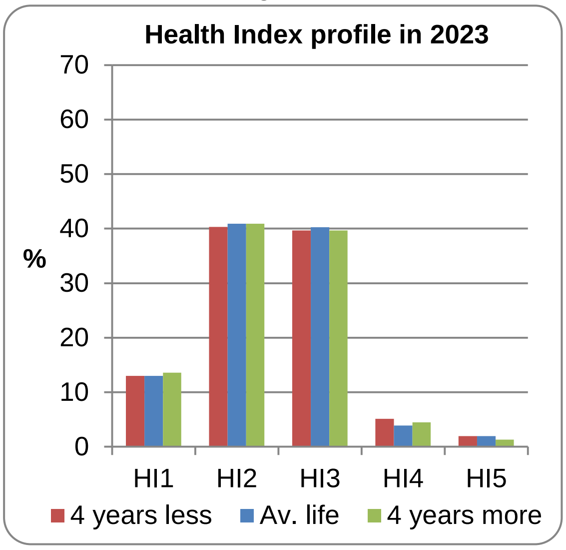
**132kV TX**



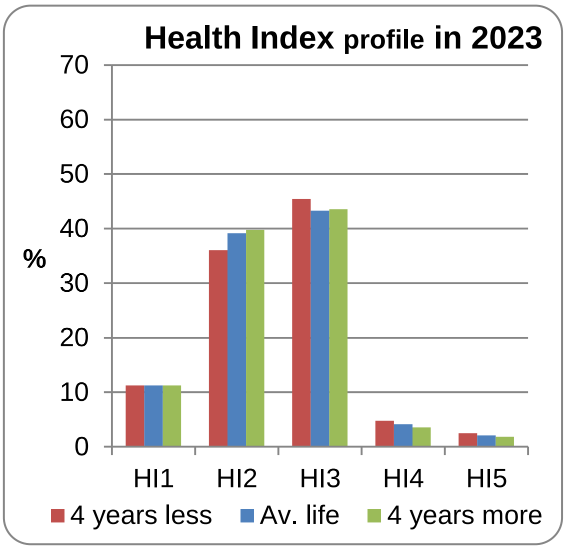

**EHV TX**



132kV TX

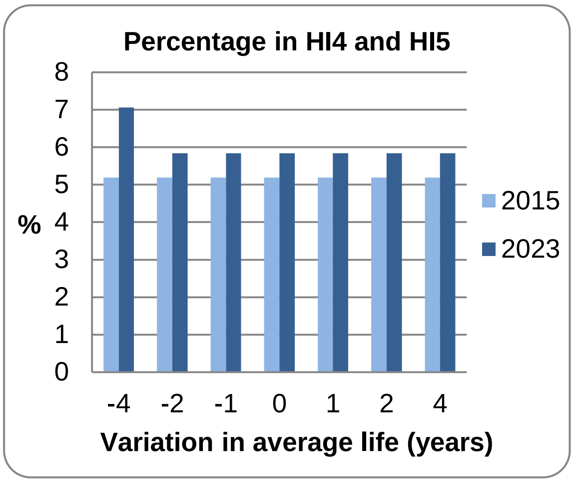



EHV TX

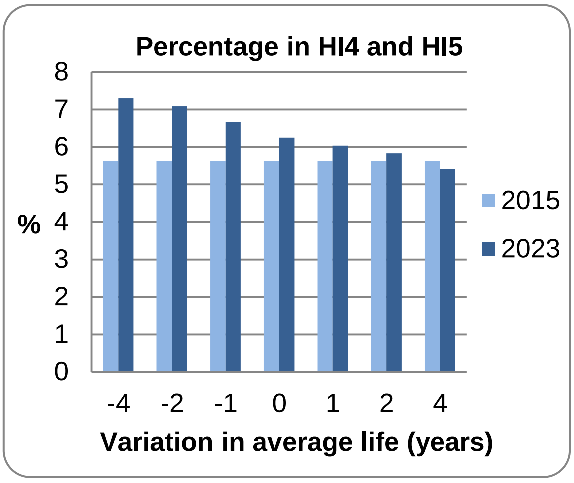



For all cases modelled, the sum of assets in Health Indices HI4 and HI5 is plotted below.

132kV TX




EHV TX




For 132kV transformers in SPN, the results show:

- An Average Asset Life variation of four years has no effect on the proportion of HI4 and HI5 assets in 2015. It will remain at 5.1%.
- In 2023, the proportion of HI4 and HI5 assets is expected to be 5.8%. An increase of four years in Average Asset Life would have no effect on this, but a decrease in Average Asset Life of four years would change it to 7.0%.

For EHV Transformers in SPN, the results show:

- An Average Asset Life variation of four years has no effect on the proportion of HI4 and HI5 assets in 2015. It will remain at 5.6%.
- In 2023, the proportion of HI4 and HI5 assets is expected to be 6.3%. An increase of four years in Average Asset Life would change this to 5.4% and a decrease in Average Asset Life of four years would change it to 7.3%.

**Conclusion**

The ED1 replacement plan for SPN transformers is robust and fairly insensitive to a variation in Average Asset Life of up to four years.

## Appendix 7 Named Schemes

The following tables show the planned replacement/refurbishment projects for ED1 with their predicted HI in 2023 and their main driver(s) for intervention.

| 132kV Transformer replacements | | | |
|---|---|---|---|
| Site | Asset | Replacement driver | Scheme Paper |
| CANTERBURY SOUTH 132 KV | GRID TRANSFORMER GT2; 009910 | FFA | No |
| CROYDON B 132 KV | GRID TRANSFORMER GT2; 009915 | FFA/condition | No |
| EASTBOURNE GRID 132 KV | GRID TRANSFORMER GT1B; 009918 | FFA/condition | No |
| | GRID TRANSFORMER GT2B; 009918 | FFA/condition | |
| KINGSTON GRID 132 KV | GRID TRANSFORMER GT1; 009926 | FFA | Yes |
| | GRID TRANSFORMER GT2; 009926 | FFA | |
| | GRID TRANSFORMER GT3; 009926 | FFA | |
| | GRID TRANSFORMER GT4; 009926 | FFA | |
| RYE GRID 132KV | GRID TRANSFORMER GT1; 009989 | Tap changer | No |
| SITTINGBOURNE GRID 132 KV | GRID TRANSFORMER GT3; 009944 | FFA | No |

| 132kV Transformer refurbishments | | | |
|---|---|---|---|
| Site | Asset | Replacement driver | Scheme Paper |
| BRIGHTON LOCAL 132 KV | GRID TRANSFORMER GT1; 009907 | Tap changer/ condition | No |
| | GRID TRANSFORMER GT2; 009907 | Tap changer/ condition | |
| GUILDFORD GRID 132 KV | GRID TRANSFORMER GT1; 009921 | Tap changer / oil condition | No |
| HORSHAM GRID 132 KV | GRID TRANSFORMER GT2A; 009924 | External condition / oil containment | No |
| | GRID TRANSFORMER GT3A; 009924 | External condition / oil containment | |
| LEWES GRID 132 KV | GRID TRANSFORMER GT1; 009930 | Tap changer / oil condition | No |
| THANET GRID 132KV | GRID TRANSFORMER GT1A; 009949 | Tap changer | No |
| | GRID TRANSFORMER GT1B; 009949 | Tap changer | |
| | GRID TRANSFORMER GT2B; 009949 | Tap changer | |

| EHV Transformer replacements | | | |
|---|---|---|---|
| Site | Asset | Replacement driver | Scheme Paper |
| ADDINGTON LOCAL | PRIMARY TRANSFORMER T1; 008301 | FFA | No |
| | PRIMARY TRANSFORMER T2; 008301 | FFA/condition | |
| BERRYLANDS 33/11KV | PRIMARY TRANSFORMER T2; 008622 | DGA | No |
| | PRIMARY TRANSFORMER T1; 008622 | DGA | |
| BRIGHTON TOWN 33 KV | PRIMARY TRANSFORMER T1; 008307 | FFA | No |
| | PRIMARY TRANSFORMER T2; 008307 | FFA | |
| EAST CROYDON 33/6.6 KV | PRIMARY TRANSFORMER T1; 008395 | FFA/condition | No |
| | PRIMARY TRANSFORMER T2; 008395 | FFA/condition | |
| GUILDFORD _A_ 33/11 | PRIMARY TRANSFORMER T5; 008521 | DGA | No |
| GUILDFORD _B_ 11KV | PRIMARY TRANSFORMER T1; 008621 | FFA | No |
| HORSELL 33/11KV | PRIMARY TRANSFORMER T1; 008535 | DGA | No |
| | PRIMARY TRANSFORMER T2; 008535 | DGA / condition | |
| HURSTPIERPOINT 33KV | PRIMARY TRANSFORMER T1; 008420 | FFA | No |
| NEWHAVEN TOWN 33KV | PRIMARY TRANSFORMER T2; 008335 | DGA / condition | No |
| NINFIELD LOCAL | PRIMARY TRANSFORMER T1; 008336 | FFA | No |
| | PRIMARY TRANSFORMER T2; 008336 | DGA / condition | |
| NORTH CHESSINGTON 33KV | PRIMARY TRANSFORMER T1; 008445 | FFA | No |
| | PRIMARY TRANSFORMER T2; 008445 | FFA | |
| NORTHIAM 33KV | PRIMARY TRANSFORMER T1; 008446 | Tap Changer / FFA | No |
| | PRIMARY TRANSFORMER T2; 008446 | Tap Changer / FFA | |
| REIGATE _A_ 33/11KV | PRIMARY TRANSFORMER T1; 008369 | DGA / condition | No |
| | PRIMARY TRANSFORMER T2; 008369 | DGA / condition | |
| | PRIMARY TRANSFORMER T3; 008369 | DGA / condition | |
| RICHMOND 33/11KV | PRIMARY TRANSFORMER T1; 008466 | FFA | No |
| ROSHERVILLE 33/6.6KV | PRIMARY TRANSFORMER T1; 008470 | Tap Changer / FFA | No |
| | PRIMARY TRANSFORMER T2; 008470 | Tap Changer / FFA / Oil Quality | |
| STEEL CROSS 33/6.6KV | PRIMARY TRANSFORMER T2; 008387 | FFA | No |
| STELRAD 33/11KV | PTX 008491 T4 | DGA / condition | No |
| SURBITON 33/11KV | PRIMARY TRANSFORMER T1; 008497 | FFA | No |
| THANET LOCAL 33/11KV | PRIMARY TRANSFORMER T1; 008349 | FFA | No |
| | PRIMARY TRANSFORMER T2; 008349 | DGA | No |
| TOWNSEND HOOK 33/6.6KV | PRIMARY TRANSFORMER T2; 008653 | DGA | No |
| WEST WICKHAM 33/11KV | PRIMARY TRANSFORMER T2; 008513 | FFA | No |
| WITHDEAN 33KV | PRIMARY TRANSFORMER T1; 008378 | FFA | No |
| | PRIMARY TRANSFORMER T2; 008378 | DGA / condition | No |

| EHV Transformer refurbishments | | | |
|---|---|---|---|
| Site | Asset | Replacement driver | Scheme Paper |
| BANSTEAD 33/11KV | PRIMARY TRANSFORMER T2; 008313 | Tap changer/ condition | No |
| CANTERBURY LOCAL | PRIMARY TRANSFORMER T2; 008597 | External condition / oil containment | No |
| CRAWLEY INDUSTRIAL EAST 33/11KV | PRIMARY TRANSFORMER T1; 008383 | Oil leaks / condition | Yes |
| | PRIMARY TRANSFORMER T2; 008383 | Oil leaks / condition | |
| DEAL PRIMARY 33/11KV | PRIMARY TRANSFORMER T1; 008389 | Tap changer / oil condition | No |
| | PRIMARY TRANSFORMER T2; 008389 | Tap changer / oil condition | |
| DOVER PRIMARY 33/11KV | PRIMARY TRANSFORMER T3; 008391 | External condition / oil containment | No |
| | PRIMARY TRANSFORMER T4; 008391 | External condition / oil containment | |
| GRAVESEND WEST 11KV | PRIMARY TRANSFORMER T1; 008511 | Oil leaks / condition | No |
| | PRIMARY TRANSFORMER T2; 008511 | Oil leaks / condition | |
| HAYWARDS HEATH 33KV | PRIMARY TRANSFORMER T1; 008415 | External condition | No |
| | PRIMARY TRANSFORMER T2; 008415 | External condition | |
| HYTHE MAIN | PRIMARY TRANSFORMER T1; 008421 | Oil leaks | No |
| KINGSTON 33/11KV | PRIMARY TRANSFORMER T3; 008325 | Tap changer/ condition | No |
| | PRIMARY TRANSFORMER T4; 008325 | Tap changer / oil condition | |
| PORTSLADE 33KV | PRIMARY TRANSFORMER T1; 008545 | Tap changer | No |
| | PRIMARY TRANSFORMER T2; 008545 | Tap changer / oil condition | |
| | PRIMARY TRANSFORMER T3; 008545 | External condition / oil containment | |
| RAINHAM MARK 33/11KV | PRIMARY TRANSFORMER T1; 008525 | Tap changer | No |
| | PRIMARY TRANSFORMER T2; 008525 | Tap changer / oil condition | |
| SHEPWAY 33/11KV | PRIMARY TRANSFORMER T1; 008644 | External condition / oil containment | No |
| SHEPWAY 33/11KV | PRIMARY TRANSFORMER T2; 008644 | Oil leaks | No |
| SHIRLEY 33/11 KV | PRIMARY TRANSFORMER T1; 008484 | Tap changer | No |
| SOUTH HOVE 33KV | PRIMARY TRANSFORMER T2; 008488 | Oil leaks / condition | No |
| | PRIMARY TRANSFORMER T3; 008488 | Oil leaks / condition | |
| TWICKENHAM 33/11KV | PRIMARY TRANSFORMER T4; 008352 | Tap changer | No |
| WOKING 33/11 | PRIMARY TRANSFORMER T1; 008526 | Tap changer | No |
| WORTHING TOWN 33KV | PRIMARY TRANSFORMER T1; 008354 | Tap changer / oil condition | No |
| | PRIMARY TRANSFORMER T2; 008354 | External condition / oil containment | |
| | PRIMARY TRANSFORMER T3; 008354 | External condition / oil containment | |
| | PRIMARY TRANSFORMER T4; 008354 | Oil leaks | |

Source: 19th February 2014 NAMP

# Appendix 8 Output NAMP/ED1 Business Plan Data Table Reconciliation

| Outputs | | Asset Stewardship Reports | | | | | | | | | RIG Table | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Investment description | NAMP Line | 2015/6 | 2016/7 | 2017/8 | 2018/9 | 2019/20 | 2020/21 | 2021/22 | 2022/23 | **Total** | RIG Table | RIG Row | 2015/6 | 2016/7 | 2017/8 | 2018/9 | 2019/20 | 2020/21 | 2021/22 | 2022/23 | **Total** |
| 132kV Transformer Replacement | 1.51.01 | 1 | 0 | 0 | 5 | 2 | 1 | 0 | 1 | 10 | CV3 | 229 | 1 | 0 | 0 | 5 | 2 | 1 | 0 | 1 | **10** |
| EHV Transformer Repalcement | 1.51.03 | 2 | 2 | 6 | 7 | 5 | 2 | 8 | 5 | 37 | CV3 | 211 | 2 | 2 | 6 | 7 | 5 | 2 | 8 | 5 | **37** |
| | | | | | | | | | | | CV3 | 212 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| 132kV Transformer Refubishment | 1.51.11 | 0 | 0 | 0 | 0 | 4 | 1 | 2 | 2 | 9 | CV5 | 52 | 0 | 0 | 0 | 0 | 4 | 1 | 2 | 2 | **9** |
| EHV Transformer Refurbishment | 1.51.11 | 3 | 2 | 5 | 2 | 4 | 4 | 6 | 5 | 31 | CV5 | 32 | 3 | 2 | 5 | 2 | 4 | 4 | 6 | 5 | **31** |
| | | | | | | | | | | | CV5 | 42 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | **0** |
| Total | | **6** | **4** | **11** | **14** | **15** | **8** | **16** | **13** | **87** | | | **6** | **4** | **11** | **14** | **15** | **8** | **16** | **13** | **87** |

*Table 26: NAMP to ED1 Business Plan Data Table Reconciliation*

*[Source: 19th February 2014 Namp Table O / 21st February 2014 ED1 Business Plan Data Tables]*

# Appendix 9 Efficiency benchmarking with other DNOs

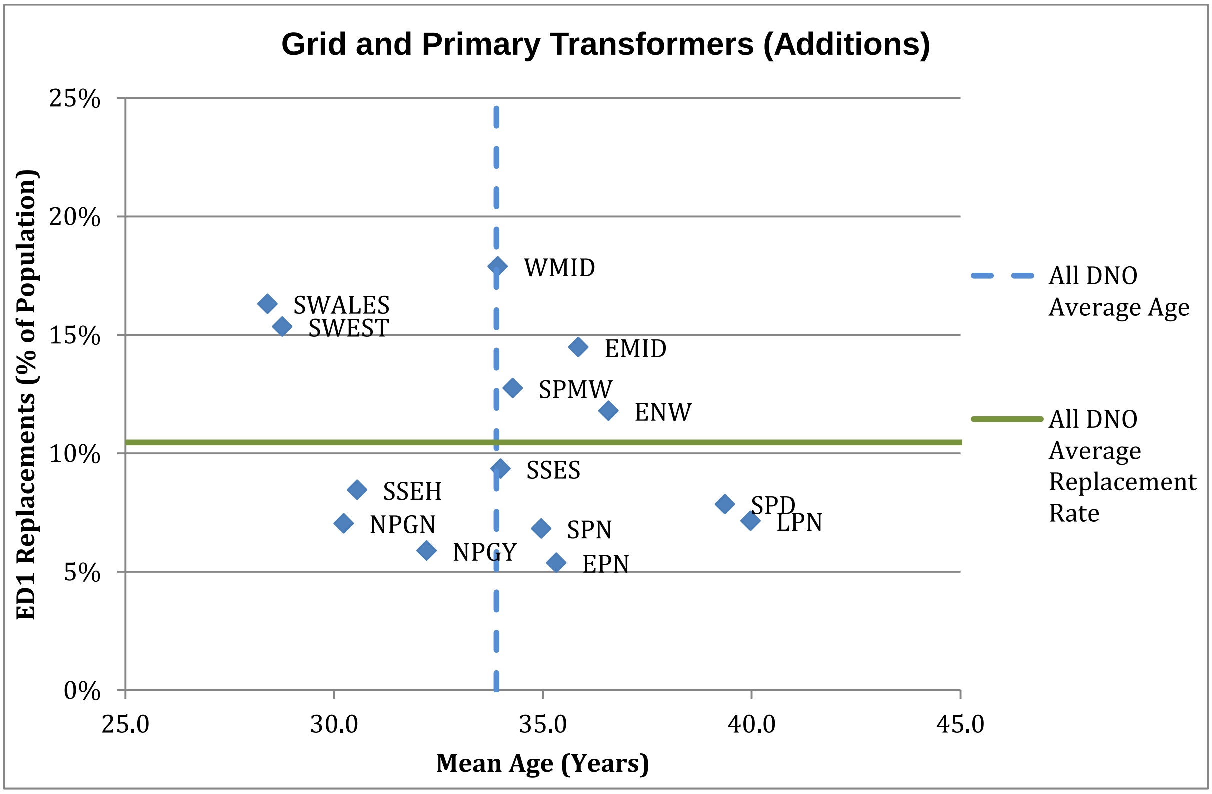



*Figure 34: All DNO asset replacement rate vs. mean asset age [Source: DNO Datashare_2013]*

The above graph shows that SPN has a lower than average replacement rate compared to other DNOs as a proportion of the asset population despite having an older than average population age. This shows that the planned investment has not been made using a solely age-based approach but by identifying the individual assets that require interventions based on their health.

# Appendix 10 Material changes since the July 2013 ED1 submission

Changes between the July 2013 submission and the March 2014 re-submission are summarised and discussed below.

| Asset type | Action | Change type | 2013 | 2014 | Difference (Reduction) | Comment |
|---|---|---|---|---|---|---|
| **33V Transformers** | Replace | Volume (Additions) | 35 | 37 | 2 | One additional project identified |
| | | Volume (Disposals) | 35 | 37 | 2 | One additional project identified |
| | | Investment (£m) | 13.3 | 13.9 | 0.6 | |
| | | UCI (£k) | 378.9 | 375.7 | (3.2) | |

*Table 27: Material Changes to July 2013 ED1 Submission (CV3)*

*[Source: ED1 Business Plan Data Tables following the OFGEM Question and Answer Process / 21st February 2014 ED1Business Plan Data Tables]*

### 33kV Transformers

The increase in 33kV Transformer additions and disposals is due to the addition of a project to replace the two transformers at Little Chart 33/11kV substation.  This followed re-evaluation of condition and load data led to the project being reassigned to NLRE from LRE.